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THE FUNDAMENTAL FACTORS CONTROLLING THE CHOICE OF STEAM ELECTRIC GENERATING STATION SITES.*

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INTRODUCTION.

The choice of the site for a steam electric power station involves both engineering and economic problems, although to many the determination of this factor of plant design seems to be very much a matter of personal choice without any underlying scientific guidance. The problem is of such broad scope, and requires so much detailed thought and knowledge, that it is possible in the time allotted to this paper to give only a general outline of some of the basic factors that must be considered, if the most economic results are to be produced.

GENERAL REQUIREMENTS FOR GENERATING STATION SITES.

There are many factors that determine the best location of a power plant. The following list contains these factors in the usual order of their importance in controlling the selection of station sites.

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(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

1. Accessibility of water supply.
2. Accessibility of fuel supply.
3. Plant size.
4. Conditions affecting transmission of power.
5. Foundation conditions.
6. Cost of land.
7. Accessibility of labor supply.

Local conditions may change the relative importance of some of the factors enumerated, or may add to the list some that in general are not of great importance. These changes can only be considered when they are involved in a specific problem, and cannot be logically introduced in a discussion of the general problem of the choice of generating station sites.

For every ton of coal burned in a steam power plant it is necessary to pump from 500 to 1,200 tons of condensing water. With this factor in mind, it can be readily appreciated that the ability to obtain sufficient condensing water is the major item in fixing a plant location.

Artificial methods of water cooling (cooling ponds, spray ponds, cooling towers, etc.) permit the utilization of sites where large bodies of water do not exist, but the investment cost and expense of operation become prohibitive except for relatively small plants. Since the plants required to serve a large power system are necessarily beyond the economic size limit for artificial water cooling, no sites will be considered suitable for station construction in the illustrative problems to follow unless adjacent to a body of water.

The amount of cooling water available continuously will determine the maximum generating capacity which can be ultimately installed at any site.

Some factors that might seem of minor importance may have a more serious economic effect than appears on the surface. Assume, as an example, railroad facilities and the topography of the country combined may apparently make the best location of the plant at the outside of a right angle bend in a river. If this stream is one that is subject to wide ranges in flow, in the winter time being full of floating ice, and during the spring freshets bringing down debris of all kinds, a careful examination may show that this is an extremely disadvantageous location since the change in direction

of the water of the river will pile ice against the intakes of the plant to the point of shutting off all the circulating water, and in the spring the same results will occur from leaves, limbs of trees and other debris. This is not merely a hypothetical supposition, for plants have been installed in locations of this type and have suffered severely during certain periods of the year from this kind of trouble. I merely cite this as an extremely important factor in the actual physical location of the plant, which can only be determined when the neighborhood of the site is known, and when the exact conditions of the location are understood.

The cost of fuel is the largest single item of operating expense of a steam generating station, thus the accessibility of a site for fuel delivery is of prime importance, and is properly placed high on the list.

The site of the plant, if possible, should be level ground where little grading is needed; adjacent to a stream or body of water of sufficient size for condensing purposes. Proper precautions against interruption of the water supply must be considered in connection with the plant's location. The topography of the surrounding country should be such that if railroad facilities are not immediately available, extensions to present lines can be made to reach the plant without undue construction expense.

The distance of the plant from the load center is of course primarily fixed by such large bodies of water as are available, even though they may not be directly in the community served. If this is the case, the transmission costs of delivering the energy into the load center must be charged against the plant site.

The first two items enumerated in the list comprise the major items controlling operating expense in the production of steam power, and therefore are major factors in fixing location. It must be remembered, however, that the annual carrying charges on the investment in plant and transmission facilities must be added to the operating costs to obtain the total cost of power delivered. Thus, it is possible for expensive plant and transmission construction to so seriously affect the economics of the situation that the first two items may be relegated to a less important place on the list.

The factors controlling the choice of the site of a stream electric generating station are so closely related to, and so greatly dependent upon, the factors determining the size of the plant, that it is impossible to intelligently discuss the former independently of the latter. Thus, although this paper deals primarily with the choice of generating station sites, it will be necessary to discuss some of the factors controlling plant size to clearly place before you the solution of the problem of the choice of plant sites.

DISCUSSION OF POWER PLANT CAPACITY REQUIREMENTS.

There is no problem of choice of site unless there is a necessity for the construction of a new plant. In general, there are two reasons for the installation of a new steam electric station:

(*a*) The need of increased plant capacity due to the increasing demands of the system.
(*b*) The installation of a new highly efficient plant to supersede old inefficient plants.

Plant Capacity Increase Due to Increased System Demands.

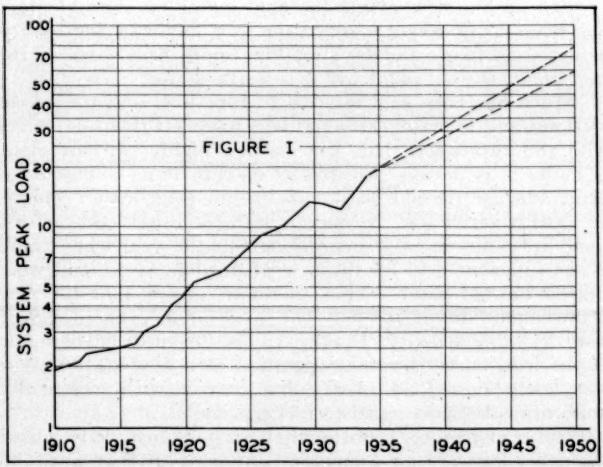
The problem of increased plant capacity due to increasing system demands is the one most generally met, and since it will suffice to demonstrate the required factors underlying the choice of sites, no further reference will be made to the second sub-item (*b*).

Let us assume, for study, a hypothetical community for which Fig. 1 might represent the load growth. Years have been plotted as abscissas on semi-log paper, and system peak in tens of thousands of kilowatts as ordinates. The solid curve represents the assumed yearly system peak loads that have been experienced by this hypothetical community.

In the early electrical development of this community it will be noted that the yearly variations are irregular, but if the years 1910 and 1934 are considered, a straight line may be drawn through their loads, which strikes a fair average for every year. This line, for purposes of estimate, has been extrapolated in the upper dotted line terminating at about 800,000 kw. Inspection shows that the rate of growth for the past four years is not as great as for the preceding twenty;

a straight line drawn through the loads of 1930 and 1934 and extrapolated is shown by the lower dotted curve terminating at about 600,000 kw. Assuming the same annual rate of growth, these two dotted curves show that in the next succeeding ten years from 1935 to 1945 the peak load on the system will have grown to a value between 400,000 kw. and 500,000 kw.

If we assume, for a matter of convenience and simplicity, that the consideration of spare equipment will be neglected,



that the power factor of units is the same as that of the load, so that the kv.-a. capacity need not enter the problem, and that the load of this community is carried at present on a plant of 200,000 kw. capacity, which is not of the latest design, then we find that in the next ten years new plant capacity of from 200,000 kw. to 300,000 kw. is required, and in the next fifteen years, with loads varying from 600,000 kw. to 800,000 kw., new plant capacity of from 400,000 to 600,000 kw. is required.

In round figures, this indicates that there is a possibility of choosing plants with ultimate capacities of 200,000 kw., 300,000 kw., 400,000 kw. or 600,000 kw.

Effect of Transmision Costs on Size.

These new plants are not to carry the entire load, but must be operated in conjunction with the existing plant. The operating costs, including fuel, labor and maintenance, must be estimated for the old and new plants with varying load factors. It must be realized that as the load factor is increased on the new plant, the load factor on the old plant will necessarily decrease, since the load factor of the load is assumed as fixed, and by supplying more base load on the new plant, the old plant will necessarily suffer.

Much has been said relative to base load and peak load stations, and in many cases speakers have left their audiences with the impression that, when a new highly efficient plant is built, it is always possible to operate it as a base load plant and use the old plant facilities for peak load. This is an ideal to strive for. However, with the usual load factors, there are hours in each day throughout the year when there is not sufficient load for the new plant alone if no load were run on the old plant. This, therefore, means that the new plant cannot run at 100 per cent. load factor even though it were desirable to do it. In other words, the effect of the shape of the load curve prevents operation of a new station as a completely base load plant—that is one with practically uniform load almost equal to its capacity.

The transmission facilities that must be installed to load the new plant are an economic consideration that must be given proper weight. Feeders will be extended from the new plant to various sub-load centers. These feeders and the new plant can be fully loaded during the maximum load period, but the ability to load the plant from these sub-load centers throughout the twenty-four hours is limited by the shape of their combined load curves. It is therefore necessary to run extra transmission facilities from the new to the old plant or to sub-load centers which, during heavy load periods, would normally be connected to the old plant. These extra feeders added to those necessary to carry only the maximum

load will give the entire transmission system a very low load factor. For this reason, the cost of loading the new plant to the maximum possible must be compared with the highest economic load on the new plant, which results when the costs of improving the load factor of the new plant are not greater than those obtained from the combination costs of the old and the new plants without this change in loading.

If the additional cost of transmission facilities to increase the load on the new plant is greater than the saving obtained by operating this increased load on the new plant, then the total cost of supplying energy will be greater, and of course is not economical, although the production costs of the new plant would be better and something that could be pointed to with greater pride, in spite of the fact that it was being done at the expense of the system as a whole.

Assuming a uniform load density, then as the plant size increases, the total cost of transmission facilities from a given plant site increases—not in a direct ratio to the size of the plant, but at a rate between the 3/2 power and the square of the plant capacity. The reason for this is that each increment of load added is farther away from the plant, and the area served is continually increasing as the distance from the plant.

With the best conditions, the cost of transmission from one 400,000 kw. plant will be about 50 per cent. more than the cost of transmission from two properly located 200,000 kw. plants. If, however, the load distribution is not uniform, then there is no definite general relation, since the controlling factor of transmission cost is the location of the more dense load areas with respect to the possible station sites.

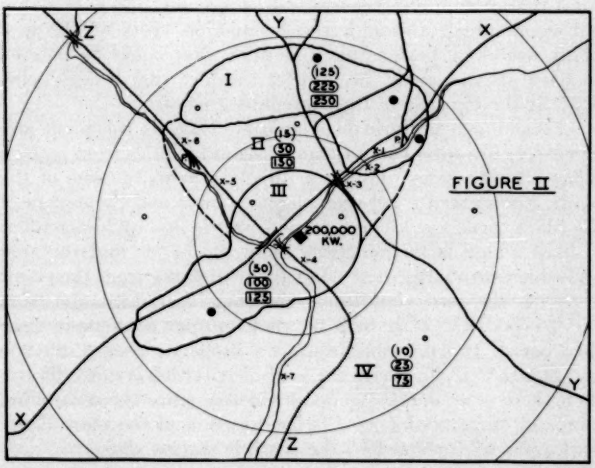
Because of the effect of transmission costs on the total cost of delivery of energy, the problem of choice of the most economical generating station site is so intimately connected with transmission that other factors being equal, this will be the controlling factor, and under no conditions can ever be properly neglected.

Effect of Load Distribution on Size.

The distribution of load in the territory, the relative density of the load in each distribution area and the distance

of each area from the load center of the whole territory have a material effect upon the choice of station sites.

A map of the hypothetical community for which the load growth curve was developed is shown in Fig. II. Two rivers join in the center of the city, which is served by three railroads, X, Y and Z, with interconnecting track facilities. The old plant is shown by a block marked 200,000 kw. in the center of the figure. The circles indicate concentric distances from the old plant, increasing in radius at the rate of two miles per circle.



The heavily outlined section marked (I) will hereafter be referred to as "Load District No. 1"; the district bounded by the lower side of No. 1 district, the two dotted lines, and the upper side of No. 3 district, will be named "Load District No. 2"; "Load District No. 3" is confined in the heavy solid line with the old plant approximately at the center, and the remaining territory will be known as "Load District No. 4." The dots show the existing substations; large solid dots represent heavily loaded substations, and small open circles

the lightly loaded substations. The figures included in brackets are the loads in each of these districts in 1935; the figures in the ovals are the district loads for 1945, and the loads included in the small rectangles are for 1950.

It will be noted that I have used the most conservative extrapolation of the growth curve. A greater rate of growth will merely bring forward the date when the capacities of these stations are required.

The distribution of the load growth as indicated in the respective territories is a matter requiring very careful study. The major increase in load growth in communities will be found along the railways and waterways. This means in Fig. II that the growth may be expected along the lines X, Y and Z.

In making this load growth estimate, it is necessary to have knowledge of the trend of manufacturing growth in the city, since it will be quite possible for the growth of load to extend along the lower section of railroads X, Y and Z, rather than in the upper section. However, the upper sections of these railroads are closer to the waterways, and for this reason I have chosen the load distribution shown, since it is probable that it would most likely develop in this manner.

In making the study of a community, load growth distribution should not be made a matter of conjecture, nor should the decision be guided too much by past growth in the various sections, since it may be that the limits of these particular sections have been fairly well reached, and the growth must, of necessity, extend into other sections.

The Chamber of Commerce, Board of Trade, Real Estate and Business Organizations, etc., of the city should be consulted relative to their activities in prevailing upon manufacturers to come to the city, and their knowledge of the trend of growth of all the communities' activities obtained. No stone should be left unturned to obtain exact information relative to the direction in which the growth of the city will occur. With as accurate data as can thus be obtained, it will be possible to allocate the load growths of the city to the sections in which they may be most likely to occur.

SITES AVAILABLE.

The railroad spurs marked "P" are shown as coal piers where railroad delivery may be transferred to barges, and barged to the plant sites if desired.

Locations X1, X2, X3, X4, X5, X6 and X7 are possible plant sites. For the purposes of this discussion, assume that a plant no greater than 200,000 kw. can be installed on sites X3, X4 and X5; that on sites X1, X2 and X6 the limit of plant capacity that can be installed is 400,000 kw., and that at site X7 a plant of any size may be installed up to the circulating water capacity of the river.

This is not an unusual condition in a city, as the available sites are usually smaller in the more densely loaded section, and increase in availability, so far as size is concerned, as the distance away from the load center increases.

To recapitulate the situation so far as plant capacity is limited by sites—

7 plants of 200,000 kw. capacity may be built,
4 plants of 400,000 kw. capacity may be built,
1 plant limited to the capacity of the river may be built.

As a development of the last item, there might be many sites available along the river where site X7 is shown. The statement that only one plant can be built of this capacity is merely to indicate that the sites available for large plants are only on this section of the river.

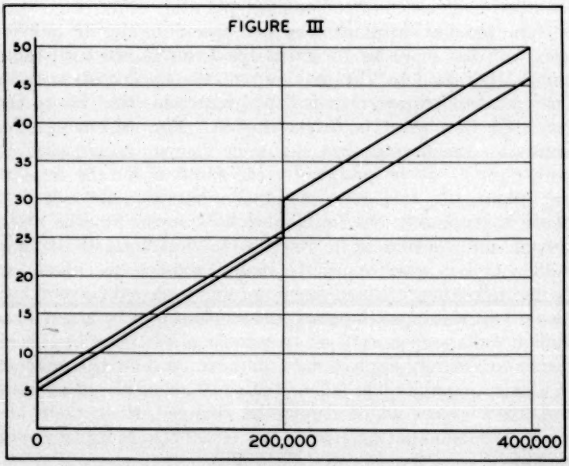
By inspection it can be seen that the average distance of transmission for practically all the sites except X7 will be about the same, when it is considered that the major growth will be along the railways.

If the major development of Load District No. 2 is along railroad Z, then transmission costs would favor the building of two 200,000 kw. plants—one in Load District No. 1 along railroad X, and one in Load District No. 2 along railroad Z. If, however, the major development of Load District No. 2 is along railroad Y, then the transmission costs would be in favor of the building of a 400,000 kw. plant along railroad X in Load District No. 1.

The foregoing discussion gives an indication of some of the limits of the choice of plant size and site. It is now necessary to consider the effect of plant size on the cost of the development.

RELATION BETWEEN PLANT SIZE AND COST.

Without going into too much detail, it may be stated that in the building of any power plant project there are some fixed costs, such as land, docks, water tunnels, etc., that depend upon the ultimate plant size, and other costs which vary as the plant capacity is increased. In Fig. III, the kw. plant capacity is plotted as abscissas, while total million dollars cost of the plant are plotted as ordinates. The fixed cost is shown by the intersection of the sloping line with



zero kw. capacity; the sloping line is shown as a fixed increment with increasing capacity. This, of course, is not true, since the units are not of infinitesimal size, and this increase must necessarily be in steps. However, this sloping line shows the actual costs for some definite capacity, depending on the size unit, and if the 200,000 kw. plant size is made up of 20,000 kw., 40,000 kw. or 50,000 kw. units, the cost will be approximately correct for capacities equivalent to the installation of one, two, three, etc., units.

The slope of the cost line will depend upon the size of units used; i.e., the larger the size of the units the lower will be the cost per kw. of capacity, and the lesser the slope of the cost line.

When a 200,000 kw. plant has been finished and it is necessary to start the construction of another 200,000 kw. plant, the same fixed investment must be made as was made for the first 200,000 kw. plant, and the line of investment costs increases vertically by the amount of this fixed cost. The increment cost is then the same as before as each unit is installed in the second 200,000 kw. plant.

The 400,000 kw. plant, which is represented by the heavier line, will cost more for its initial fixed charge, since all those things that go into the make-up of the fixed cost, such as land, water facilities, etc., will be greater in cost, due to the fact that they must be larger in size. The increment cost, however, considering that the same size units are used in both plants, will be practically the same as for the 200,000 kw. plant. It has been assumed that the 400,000 kw. plant costs about one million dollars more for the fixed charge and continues, in its construction cost, to be one million dollars more expensive than a 200,000 kw. plant, up to the time when it is necessary to build a second 200,000 kw. plant. At this time the 400,000 kw. plant will be about four million dollars cheaper than two 200,000 kw. plants. These figures are merely approximate, and are used for the purpose of illustrating the idea, rather than to be considered as hard and fixed factors which cannot be changed, since there are many variables that determine the actual cost of a plant that cannot be considered in this discussion.

The installation of two 200,000 kw. plants will have a smaller transmission cost to the sub-load centers than the single 400,000 kw. plant, since the plants will be in different locations and will have a shorter average transmission distance.

In round figures the transmission of one kw. for one mile by 13,000-volt underground cables costs about $3.50 for transmission investment.

It is reasonable to assume that the transmission cost for 200,000 kw. transmitted from the 400,000 kw. plant will be

the same as this amount of power transmitted from one 200,000 kw. plant, and that the remaining 200,000 kw. from the 400,000 kw. plant will have to be transmitted a longer distance, since this plant is further removed from the sub-load centers than the second 200,000 kw. plant would be. When it is considered that a saving of four million dollars is made in plant investment and that to transmit 200,000 kw. for a mile would cost $700,000, it can be readily seen that before the increased transmission cost would balance the plant capital saving, it would be necessary for the increased transmission distance to be 5.7 miles.

The increased losses and greater operating cost of the longer distance of transmission would, in effect, cut down the mileage that the load could be transmitted from the 400,000 kw. plant before an economic balance was reached, but this mileage would again be increased by the reduced operating costs obtained through the operation of one plant instead of two, so that it is fair to say, for the purpose of argument, that the choice should be for the construction of a 400,000 kw. plant rather than two 200,000 kw. plants, as inspection shows that up to a 400,000 kw. capacity, the increased distance of transmission would not approach five miles.

If, however, the extra transmission distances were close to, or over, five miles, it would be necessary to consider the increased transmission losses and operating costs as balanced against the lower plant operating costs, before an exact decision could be made as to the size of the plant.

It is desirable to look further ahead to determine if a still larger plant than 400,000 kw. should not be built.

It is assumed that there will be about a five million dollar differential in favor of an ultimate 600,000 or 800,000 kw. plant as compared to two ultimate 400,000 kw. plants, with the same installed capacity. However, if we return to Fig. II we will note that site X7 is much farther from the load centers than any one of the other sites, and that up to the time the second 400,000 kw. plant is built, the larger plant costs a million dollars more, and the transmission facilities for about 300,000 kw. of the load, for approximately five miles extra length, cost about five million dollars more for transmission, or a total of six million dollars more for the larger plant.

After the second 400,000 kw. plant is started, the load growth will be increasing toward 800,000 kw., and the possibility is that some of the expansion will come in Load District No. 4, thus decreasing the average distance of transmission from site X7, and the increased energy developed at site X7 will be transmitted at a decreasing differential cost of transmission as compared to the 400,000 kw. plants, due to a decrease in the average distance of transmission between this plant and the two 400,000 kw. plants.

TABLE I

SAVINGS OF 600,000+KW. PLANT
COMPARED TO TWO 400,000 KW. PLANTS

CAPACITY REQUIRED	400,000 KW.	600,000 KW.	800,000 KW.
DIFFERENCE IN PLANT INVESTMENT COST	+$1,000,000.	-$5,000,000.	-$5,000,000.
DIFFERENCE IN TRANSMISSION INVESTMENT COST	+$5,200,000.	+$4,000,000.	+$3,500,000.
TOTAL DIFFERENCE	+$6,200,000.	-$1,000,000.	-$1,500,000.

- = IN FAVOR OF 600,000 + KW. PLANT

+ = AGAINST 600,000 + KW. PLANT

I have shown in Table I the savings to be obtained by the building of a 600,000 kw. plant that can later be extended to 800,000 kw. as compared to two 400,000 kw. plants. The difference in plant investment cost, the difference in transmission investment cost and the total difference are shown for capacities required of 400,000 kw., 600,000 kw., and 800,000 kw. The assumption has been made that there will be about 1,500,000 kw. miles of additional transmission required from the ultimate 600,000 kw. plant when the capacity required is 400,000 kw.; 1,150,000 kw. miles of

additional transmission when the required capacity is 600,000 kw., and 1,000,000 kw. miles when the plant has been extended to 800,000 kw. capacity. It will be noted that while the 600,000 kw. plant shows an increase in plant investment as compared to one 400,000 kw. plant, for the larger capacities required it shows a decrease of five million dollars in plant investment cost, and the transmission investment cost decreases as the capacity required increases, so that while the total investment is greater for the requirement of 400,000 kw. capacity, it is less for the larger capacity requirements.

The difficulty of accurately predicting the direction of load growth is such that with the small savings to be obtained from the installation of a 600,000 kw. plant, even with the larger loads, and the most favorable direction of growth, it would be an error in judgment for this specific problem to choose the large plant, particularly when it is considered that a slight change in the direction of growth would reduce the savings indicated, and that greater continuity of service is assured with two plants.

From the foregoing discussion it is quite evident that the decision should be made in favor of two 400,000 kw. plants ultimately and one 400,000 kw. plant initially for this particular problem.

Attention is called to the fact that the figures that have been used are the ultimate capacities of the plants to be installed, and not the initial installation, as it would by no means be economic in the problem here considered to immediately install a 400,000 kw. plant, since there is no load demand that would warrant it. The choice is made of the ultimate plant capacity and the present needs of the situation must be made to fit in to this ultimate plan.

CHOICE OF SITE.

Referring again to Fig. 11, and remembering that sites X_3, X_4 and X_5 have been eliminated, due to the choice of the 400,000 kw. plant, since they are insufficient in extent to accommodate this size plant, the choice is narrowed down to sites X_1, X_2, X_6 and X_7. The reasoning that eliminated the 600,000 kw. plant at site X_7 from further consideration also eliminates this site as a proper one for a 400,000 kw.

plant. It was assumed that the maximum increase in load was in Districts Nos. 1, 2 and 3, and the total load in Districts Nos. 1 and 2 much greater than in No. 3. With site X2 on the opposite side of the river from the major part of these loads, the choice would be confined to sites X1 and X6 unless site X2 presented so many valuable characteristics other than that of transmission that it could not be neglected.

Assuming that the river has a sufficient flow of water to accommodate a 400,000 kw. plant in both its branches, site X1 would be chosen, since it is nearer the bulk of the load, and would require the least transmission cost.

The foregoing discussion is based upon transmission considerations alone. It will be noted that both sites X1 and X6 are equally well situated in so far as fuel delivery is concerned, both by rail and by water, provided that Z and X are both fuel shipping roads. If Z and Y are the fuel shipping roads, then site X1 is penalized by rail, although fuel from road Y could probably be trans-shipped outside of the urban district and brought into the Pier P near X1, which would place site X1 on a par with site X6 so far as trans-shipping by water is concerned.

After obtaining exact data on the cost of fuel delivered, as balanced against the cost of power transmission, and assuming that in other respects the costs for both sites are the same, the choice can be made between sites X6 and X1.

Even though the fuel shipment costs were somewhat higher for site X1, a prediction of rapid load growth in Load District No. 4 with the comparative transmission costs from sites X1 and X6 might show a balance in favor of site X1.

Foundation conditions, circulating water difficulties, cost of land, and similar factors, must be carefully considered after the choice has been narrowed down to these two locations by the general considerations outlined. These problems can only be solved when the exact conditions existing are known, and there are so many of these that it is impossible to generalize on them.

CAPACITY LOCATED AT DISTANT COAL MINE.

In arranging for additional capacity to supply the needs of an urban community so located that transmission from the

coal mining district is possible, it is necessary to consider the relative economy of a plant built near the center of load, as against a plant built at the mines and transmitting energy to the load center.

Many more sites are available in the country along the rivers adjacent to the coal mining territory. Since it is in comparatively open country and a long distance transmission line may be moved at the generating station end over a fairly wide range in mileage without affecting its distance to the load center, the determination is between the location of a plant at the mine as against a plant at the load center, and not the specific site of the mine plant.

CHOICE OF MINE OR LOAD CENTER PLANT.

The question to decide is whether a plant should be built in this community, or in the mining regions, assuming that the mining regions are, in one case, 100 miles, and in the other, 200 miles distant from the community. Both the new steam plants to be installed will be highly efficient. The plant at the load center, since it is using more expensive fuel, must, of necessity, be of more efficient, and therefore of more expensive design.

Ordinarily there is not sufficient water supply for condensing purposes for a large plant in the immediate vicinity of coal mines, so that it would probably be necessary to locate the plant on a river some distance from the mines, and thus involve railroad haulage of the coal for some distance.

The size of the plant located at the mine is not limited by the local transmission facilities in the community served, since the long distance transmission must necessarily terminate at one point and therefore the limits are primarily due to the factors affecting the choice of site. The cost of the long distance high voltage transmission facilities much overbalances the cost of local transmission facilities, and although the increased cost of local transmission, as compared to that for a load center plant, must be charged against the plant at the mine, it does not affect the choice of site.

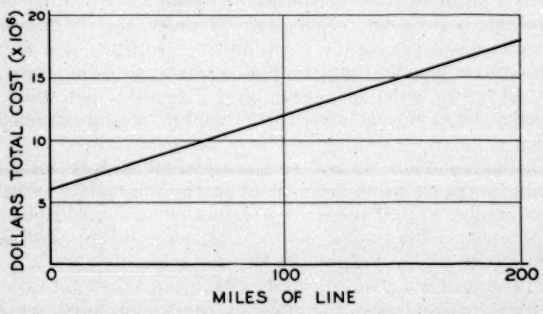
For convenience, the old plant at the load center will be called plant "A," the new plant at the load center "B," and the new plant in the coal regions "C."

A choice between a plant at the mines and a plant at the load center narrows down to the economies of the situation with this exception,—that should the cost be equal, the mine location would be automatically eliminated, because of the extra hazard of long distance transmission.

For simplicity, assume that the cost of local transmission facilities from power plant B to the sub-load centers is the same as that from the step-down substation of the mine plant to the sub-load centers. Assume that plant B will have an

FIGURE IV

INVESTMENT COST FOR TWO SINGLE 200 KV. LINES WITH STEP-UP AND STEP-DOWN SUB-STATIONS



ultimate capacity of 400,000 kw. with only 200,000 kw. installed at the time the economic comparison is made. In order to provide for transmission line losses between the mine plant and the step-down substation, assume that the mine plant located 100 miles from the station will have a capacity of 420,000 kw. and that the mine plant located 200 miles from the station will have a capacity of 440,000 kw. and that only half of the total capacity in each plant will be installed at the time this comparison is made. The increase in mine plant capacities provides 5 per cent. and 10 per cent.

respectively for transmission losses for the plants located 100 and 200 miles from the station. The cost per kw. of the urban plant is assumed to be $130, and because of its location and cheaper fuel the cost of the mine plant is assumed to be $110 per kw. This figure becomes $115.50 and $121 respectively per kw. delivered for 100 and 200 miles' transmission distance.

The cost of high voltage transmission from the mine plant is shown in Fig. IV and includes the step-up and step-down substations, synchronous condensers, etc., for transmission

TABLE II

INVESTMENT COSTS FOR POWER PLANTS

	A	B	C (100)	C (200)
PLANT INVESTMENT COST PER KW.	80	130	115.5	121
TOTAL PLANT COST	16×10^6	26×10^6	23.1×10^6	24.2×10^6
TRANSMISSION COST (FIG. IV)			12×10^6	18×10^6
TOTAL			35.1×10^6	42.2×10^6
YEARLY INVESTMENT CHARGE (15%)	2.4×10^6	3.9×10^6	5.27×10^6	6.34×10^6

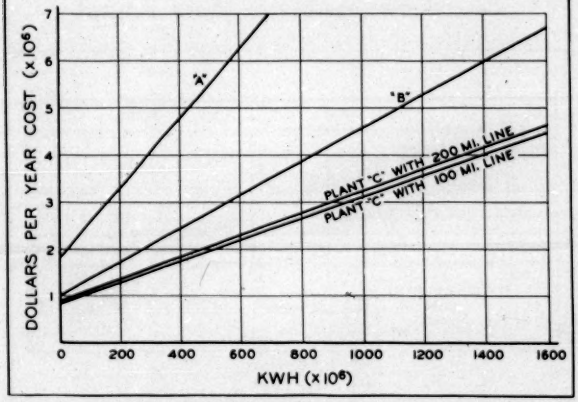
mileages ranging from 0 to 200 miles. Table II shows the plant investment costs per kw. and total plant costs for plants A, B and C, together with the transmission costs for plant C. It also shows the yearly investment charge at 15 per cent.

To make an individual comparison, it is necessary to include the investment and operating costs of plant A. The operating costs must be included, since they will vary with the method of operating the plant, but it might seem at first thought that the investment cost of plant A could be excluded,

since it is the same in all cases, and would not affect the cost differential between different plants. If, however, the investment cost of plant A is omitted, an erroneously low cost for plant A would be shown as compared to plants B and C, and this would give a misleading idea as to the relative values of the plants. Also, instead of knowing the total operating and investment cost figures, these figures would be less by the investment cost of plant A, and an erroneous value for the cost per kw.-hr. would be obtained.

FIGURE V

TOTAL YEARLY OPERATING COSTS FOR PLANTS A, B & C



Taking into consideration freight, fuel handling and the cost of the coal at the mines, it will be found that the equivalent fuel cost at the "at-the-mine-plant" is about $2.50 per gross ton, as compared to $6.00 per gross ton of coal at the seaboard.

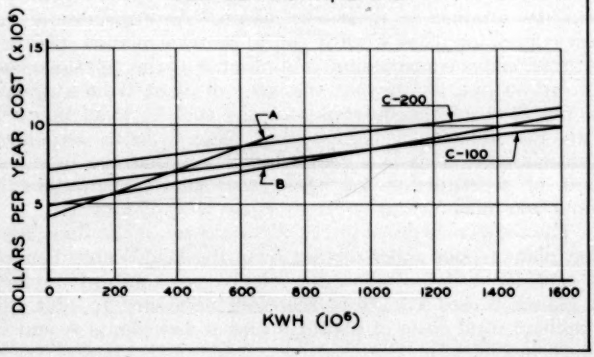
In Fig. V the yearly kw.-hr. loads on the plants have been shown as abscissas, and the total million dollars' cost per year of plant operation as ordinates. These costs have been included for plants A, B and C, the cost of plant C being

corrected for 5 per cent. loss for the 100 miles transmission, and 10 per cent. loss for the 200 miles transmission.

The operating and maintenance cost less fuel will be almost the same for plants B and C. The fuel cost is much lower for plant C, however, and this is the item that makes the great difference in the total operating costs of the plants. The total cost of energy delivered by the plant is made up of two factors, the operating cost and the investment cost. If the yearly investment cost shown in Table II is added to the total operating costs shown in Fig. V, the total yearly costs are obtained. These are plotted in Fig. VI.

FIGURE VI

TOTAL OPERATING AND INVESTMENT COSTS PER YEAR FOR PLANTS A, B & C



The increment costs of the plants have not been changed. The increment cost lines have merely been moved vertically in amount equal to the yearly investment cost. The reason that the slope factors do not appear to be the same in Figs. V and VI is because the ordinate scale has been increased about twice, while the abscissa scale has remained the same. Due to its low investment cost on very low load factors, where the operating cost is comparatively insignificant, plant

A is cheaper to operate than plant B up to about 200,000,000 kw.-hr. per year; it is cheaper to operate than plant C with 100 miles transmission up to about 400,000,000 kw.-hr. per year, and is cheaper than plant C with 200 miles transmission up to 600,000,000 kw.-hr. per year. Also, plant B is cheaper to operate than plant C with 100 miles transmission up to about 1,000,000,000 kw.-hr. per year, and is cheaper to operate than plant C with 200 miles transmission at any load factor.

These estimates show that consideration must be given to plant C with 100 miles transmission as compared to a plant directly at the load center, but if plant C is 200 miles away, it need not be considered.

A 200,000 kw. plant operating at 90 per cent. load factor will produce 1,575,000,000 kw.-hr. per year, and as it has been assumed for this problem that the total peak is 400,000 kw., it is evident that this is the absolute practical limit that could be obtained on these new plants. An inspection of the cost curves for plant C with 100 miles transmission, plant C with 200 miles transmission, and plant B at the 1,575,000,000 kw.-hr. output, shows that the costs of plant B lie at about 60 per cent. of the difference of the cost between plant C with 100 miles transmission, and plant C with 200 miles transmission. This is a rough indication that the practical limit of transmission for these particular assumptions is about 160 miles.

The total costs given in Fig. VI, however, while they show that plant C, 200 miles distant from the load center, cannot be considered, do not show the relative economic advantages of plants B and C. It is therefore necessary to plot the combined total costs of plants A and B and plants A and C shown in Fig. VII.

The total cost of operation of these plant combinations will vary with the load on the respective plants, since the total load on the system is fixed, and if load is put on one plant, it must be taken off the other. The loads on plants B or C have been plotted as abscissas. The load on plant A is, of course, the difference between 1,400,000,000 which is assumed as the kw.-hr. load of the system and the load on plants B or C. The total cost of plant A, with various loads, in

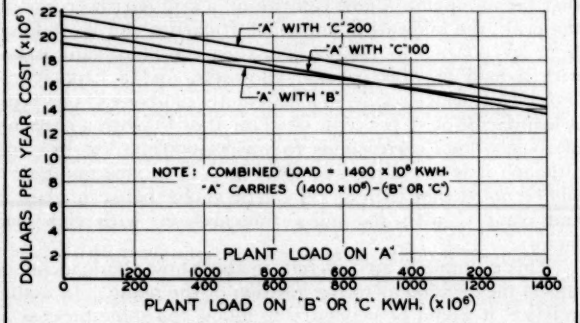
combination with the costs of plants B or C have been plotted as ordinates.

Loads on plant A greater than 1,000,000 kw.-hr. per year are of academic interest only as it would be impractical and uneconomic to carry out this operation, and it is only so plotted to make the curves continuous.

As the load is removed from plant A and put on one of the new plants, the total cost of operating the system continuously decreases, and reaches the minimum when all the load is

FIGURE VII

TOTAL COSTS PER YEAR
FOR PLANT COMBINATIONS INDICATED



carried on the new plant. This, however, cannot be done since the new plant is only capable of carrying 200,000 kw. maximum load, and there is a fair percentage of the total kw.-hr. between the 200,000 kw. load and the maximum load of 400,000 kw. If we assume that for the year the kw.-hr. in this range are about 200,000,000, then the maximum load that can be put on the new plants is 1,200,000,000.

The ordinate at this point shows that plant C with 100 miles transmission gives a slightly lower cost than plant B located at the load center, and that plant C with 200 miles

transmission costs more than plant B. Therefore, if it is possible to locate plant C within the radius of 100 miles from the load center, it would seem to be the logical choice, with the conditions as assumed.

One of the assumptions on which these figures are based is that the total load is 400,000 kw. Since the load factor of this system has been assumed to be 40 per cent, and since the load on the new plant is 68.5 per cent., it will be realized that when a load of 600,000 kw. is reached, the load factor of the new plant will, of necessity, be less, as it takes care of a greater share of the peak with a correspondingly smaller increase in kilowatt-hours. For a rough comparison, if the load factor of the 600,000 kw. load is 40 per cent., the total load on the system will be 2,100,000,000 and if it is assumed that because plant A now can run on a still narrower part of the peak, the kilowatt-hours which it carries can be reduced from 200,000,000 to 100,000,000, then the new plant is left with a load of 2,000,000,000 kilowatts, and a capacity of 400,000 kw. which results in a load factor of about 57 per cent. A load factor of 57 per cent. on plant B or C (with a capacity of 200,000 kw.) corresponds to a 1,000,000,000 kw.-hr., and although it is not correct to use Fig. VII in this manner, it will be noted that there is very little choice between plant B and plant C with 100 miles transmission, with this load factor.

This example is used merely to show how the load factor affects the decision as to the location of the plant. In actual practice, it would be necessary to follow the same process as has been outlined in Table II and Figs. IV and VII inclusive for the 600,000 kw. load, which requires a new 400,000 kw. plant, to determine whether plant C or plant B were the most economic one to build.

In considering the projected load when it has reached a value of 600,000 kw., the possibilities of improving the load factor must be carefully weighed, since, if it is possible to increase the load factor considerably above the one that has been assumed, then the plant at the mine mouth will make a better showing. If it is not possible to increase the load factor, or, if the load factor decreases, this will correspondingly affect the economics of the plant with long distance transmission.

CONCLUSION.

I wish to emphasize that the figures used in this paper are only approximately correct. They have been purposely chosen arbitrarily so that the effect of various factors could be demonstrated. As an example, should the construction cost of the plant at the mines have been assumed $125 per kw. instead of $110 per kw., the total cost line of plant C in Fig. VII would always be greater than plant B, and the effect of load factor on the choice of site would have disappeared.

It must not be assumed that because in this particular case I have shown that for a plant of 200,000 kw. capacity there are some conditions of operation which favor the choice of a plant at the mine that this will always be the case. The choice was practically limited to a distance of 100 miles from the load center, and resulted from the assumption of a relatively lower plant construction cost. There is the additional possibility that plant C might be more expensive, or *as* expensive, when its capacity was increased to 400,000 kw.; thus, with equal economies the choice would, of course, be in favor of the plant at the load center since the hazard of a long distance transmission line is eliminated.

The assumptions of definite figures have been made because the underlying principles affecting the choice of the site of a power plant can be more clearly illustrated and understood if a definite problem is given, than if the general facts are stated without a concrete demonstration, even though a concrete demonstration is dangerous, in that it is apt to lead to ill-considered general conclusions because definite figures are used.

The variation in construction costs, of power plants with variation in capacity and type, of long distance transmission with variations in length and capacity, and of local transmission with variations in length and capacity, are much more complex than the charts presented indicate. The subject of this paper is related entirely to the choice of steam generating station sites, and the subject matter of cost variation has been introduced only to show the effect of these factors upon the choice of site. The relation of the construction cost of any one of the aforementioned factors to the many variables

affecting and controlling it is a subject of individual discussion for each of these factors which would, in itself, be more involved and lengthy than the subject matter of this paper. An illustration of this is the effect which the choice of heat cycle on which the plant is to operate or the size of turbo-electric units have upon the plant cost.

Likewise, the variation in operating cost with plant capacity and output, while much more complex than indicated by the straight line relations shown in Fig. V, have been simplified for the purposes of this paper, and indicate the method of attack rather than concrete, comparative costs.

I cannot impress upon you too strongly the fact that each problem must be considered on its own merits, that the factors that I have given must be evaluated for each problem, and the conclusions must be reached from the facts that are obtained, and not be based upon general theory, general statements, or conclusions drawn from the solution of some one definite case problem, founded upon assumption that may have no relation to the specific case under consideration.

THE TEMPERATURE COEFFICIENT OF PHOTOGRAPHIC SENSITIVITY. PART II. EFFECT OF LOW TEMPERATURE ON THE PHOTOGRAPHIC ACTION OF ALPHA-PARTICLES.*

BY

S. E. SHEPPARD, T. R. WILKINS, E. P. WIGHTMAN, AND R. N. WOLFE.

Communication No. 590 from the Kodak Research Laboratories.

In Part I of these investigations,[1] which dealt with the effect of low temperatures on the natural and optical sensitivities of photographic plates to blue and red light, it was stated that: "It seems possible that further insight into the nature of the sensitivity drop at very low temperatures may be obtained . . . by examining the effect of x-rays or α-particles. This is independent of sensitivity nuclei [and we may add also of dye sensitizing] and only determined by the projective area [of the grains]."

Not much systematic work has been done in the past on the effect of temperature on the photographic action of α-particles. Eggert and Luft [2] claim that the sensitivity of the emulsion is practically independent of the temperature at which exposure is made. As we shall see later, this is not true at very low temperatures, if one uses "contrast" in addition to the reciprocal of the relative inertia as a factor in the measure of relative speed, or the reciprocal of the relative amount of exposure required to produce with standard conditions of development, say a density of 1.00 as a measure of relative average sensitivity.

Most of the investigators on the photographic action of α-particles have not dealt with the effect of temperature.

* Presented at meeting of the Optical Society of America, Philadelphia, Pa., October, 1935.

[1] Sheppard, S. E., Wightman, E. P., and Quirk, R. F.: *J. Phys. Chem.*, **38**, 817–31 (1934).

[2] (*a*) Eggert, J., and Luft, F.: *Z. physik. Chem.*, Bodenstein Festband, 745–54 (1931); (*b*) *Veröff. wiss. Zentral-Labs. Agfa*, **2**, 9–18 (1931); (*c*) *Ibid.*, **3**, 258–63 (1933); (*d*) Luft, F.: *Phot. Korr.*, **69**, 161–5 (1933).

The experiments of Kinoshita [3] in 1910, indicated that each grain of silver halide hit by an α-particle is made developable. Later, Svedberg and Andersson [4] and still later Eggert and Luft [2] have given further experimental confirmation of this. Kinoshita, from his experiments with multiple strata of single grain-layer plates, exposed and developed separately, derived the equation:

$$D = D_{max.} \cdot (1 - e^{-c_1 N}), \qquad (1)$$

in which N is the number of α-particles striking the plate in a time t; c_1, the probability constant; $D_{max.}$, the maximum density obtainable; and D, the density corresponding to the given exposure N.

Wilkins and Wolfe [5] found that equation (1) holds also for commercial emulsions under certain conditions, that is, with collimated α-rays falling perpendicularly on the emulsion. They found that the probability constant c_1 should be the same for thick and for thin emulsions and should equal $\pi\rho^2 = k/S_0$, ρ being the cylinder radius within which a single α-particle makes all grains developable to a depth δ (the residual range of the α-particle) and S_0 the number of grains below 1 square centimeter of the emulsion which is k grains deep. The photographic densities in their experiment did not exceed 3.5.

In the present studies, the polonium source was placed almost on the emulsion so that, when comparative exposures were made at room and liquid-air temperatures, no considerable reduction in range would occur. With a diffuse source placed in this way, the α-rays are incident at all angles within nearly 180° and the cross-firing thus produced makes a grain liable to be hit more than once. But since it needs only one hit to make a grain developable, all those particles not producing an initial hit of any one grain are of no value so far as that grain is concerned. It should be stated, however, that it is not known just what effect the multiple hitting of a grain has on its rate of development.

When an attempt is made to fit equation (1) to data of a process emulsion for exposures of a diffuse source close to the

[3] Kinoshita, S.: *Proc. Roy. Soc.*, **A83**, 432–53 (1909–10).

[4] Svedberg, T., and Andersson, H.: *Phot. J.*, **61**, 325–32 (1921).

[5] Wilkins, T. R., and Wolfe, R. N.: *J. Optical Soc. Amer.*, **23**, 324–32 (1933).

film, such as those given below, where not only were the α-rays incident at all angles but also where the exposures were prolonged until at least 99 per cent. of the grains had been affected, giving densities as high as 4.93, c_1 does not stay constant but decreases, until for the longest exposures c_1 is only about 10 per cent. of its value for short exposures. In the case of the panchromatic emulsion, c_1 does not decrease steadily but rises, passes through a maximum, and then falls. An apparently adequate procedure is indicated in the following analysis for the case of complete development and is tested both for a fine-grain process and also for a more complex double-layered panchromatic emulsion.

The increase in the number of grains made developable by an α-ray is, at first k (where k = number of grains encountered by a ray of a given range). Later, the number of new grains will be less than k because some will be hit for the second time. The increase in the number of developable grains will, however, be the same fraction of the full complement k as the number of grains still unhit is of the total number of grains in the emulsion. Thus,

$$dG = \frac{G_m - G}{G_m} k\, dN, \tag{2}$$

where G = number of grains already hit, G_m = number of grains in the emulsion, and dN = number of α-rays. Integrating,

$$G = G_m(1 - e^{-k(N/G_m)}). \tag{3}$$

If we make the usual assumption that the photographic density is proportional to the number of grains made developable, we get

$$D = D_m(1 - e^{-k(N/G_m)}), \tag{4}$$

an equation similar to (1) which, as has been indicated above, does not fit the data.

An obvious explanation of this lack of agreement is that the exponent in (3) should be a function of the number of grains made developable rather than of the number of α-rays which have fallen on the emulsion. These will be proportional only when the number of grains already affected is so small

that each impinging α-ray still gets the full quota of k grains. A relation

$$D = a\,G_m(1 - e^{-G/G_m}) \tag{5}$$

is therefore assumed. If $G/G_m = 0.1$, the bracket differs from G/G_m by only 1/2 of 1 per cent. and

$$D = a\,G \tag{5'}$$

within this limit, but for longer exposures, the density is reduced because each successive particle is affecting fewer and fewer grains. The constant $a\,G_m$ can be expressed in terms of D_m, for when $G = G_m$ then $D = D_m$ and from (5)

$$D_m = a\,G_m(1 - e^{-1}) = a\,G_m\left(1 - \frac{1}{2.718}\right),$$

whence $a\,G_m = 1.57\,D_m$, and equation (5) becomes

$$D = 1.57\,D_m(1 - e^{-G/G_m}). \tag{6}$$

This with

$$G = G_m(1 - e^{-k(N/G_m)}) \tag{3}$$

now serves instead of the single equation (1) heretofore used.

Process Emulsion.—Tables I and II give data for a Kodak Process emulsion at 20° C. and at − 185° C., and the densities as calculated from (3) and (6) are also given. For densities greater than the fog density, the agreement is about as satisfactory as could be wished for, especially when one considers that the fog correction at best is a somewhat arbitrary procedure.[6] To appreciate the difficulty of accurate readings of high densities, it may be recalled that a density of 4 means an opacity of 10,000 and hence a transmission by the developed plate of only 1/10,000 of the light incident on it in the densitometer, and for the lowest densities in Tables I and II, the fog correction is of the order of 90 per cent. of the observed density. The agreement of the last two columns in each case is quite satisfactory as may be seen also in Figure 1.

A comparison of equation (3) with the Kinoshita equation indicated that k/G_m is equal to c_1, the average grain size of the

[6] Wilsey, R. B.: *Phot. J.*, **65**, 454–8 (1925). Pritchard, H. A.: *Ibid.*, **67**, 447–59 (1927).

TABLE I.

Process Emulsion, 20° C.

Time of Development, 12 mins. in 1 : 1 Pyro Soda at 20° C.

$\overline{\pi r^2} = 0.366\mu^2$.* $G_m = 2.71 \times 10^9$/sq. cm.

$D_m = 5.0$. $k = 10$.†

Fog = 0.33. $k/G_m = 0.37 \times 10^{-8}$ cm^2.‡

$N \times 10^{-6}$	kN/G_m	e^{-kN/G_m}	$G/G_m = 1 - e^{-kN/G_m}$	e^{-G/G_m}	$\frac{D}{1.57\ D_m} = 1 - e^{-G/G_m}$	$D_{obs.}$	$D_{corrected\ for\ fog}$	$D_{calcd.}$
1.66	0.006	0.994	0.006	0.994	0.006	0.42	0.096	0.047
2.64	.0098	.990	.010	.990	.010	.46	.14	.079
4.20	.0155	.985	.015	.985	.0155	.50	.18	.125
6.60	.0243	.976	.024	.976	.024	.57	.26	.19
10.6	.039	.962	.038	.963	.037	.67	.36	.29
16.6	.060	.942	.058	.944	.056	.82	.52	.44
26.4	.098	.907	.093	.911	.089	1.03	.75	.70
52.8	.195	.823	.177	.838	.162	1.54	1.30	1.27
105.6	.39	.677	.323	.724	.276	2.28	2.09	2.16
211.0	.78	.458	.542	.582	.418	3.24	3.12	3.28
422.0	1.56	.211	.789	.454	.546	4.29	4.24	4.30
660.0	2.43	.0882	.912	.402	.598	4.63	4.60	4.70
1060.0	3.92	.0198	.980	.375	.625	4.79	4.74	4.90
1660.0	6.13	.00218	.998	.369	.631	4.88	4.87	4.95
2640.0	9.74	.000059	.999941	.368	.632	4.93	4.92	4.96
4200.0	15.50			.368	.632	4.95	4.95	4.96

* Microscopically determined.

† Microscopically determined by measurement of the α-ray tracks.

‡ It is to be noted that this value agrees with the grain size, $\overline{\pi r^2}$, determined independently.

TABLE II.

Process Emulsion, −185° C.

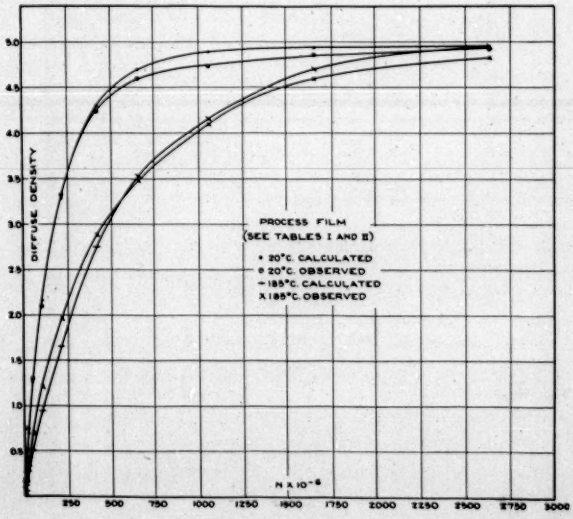
Time of Development 12 mins. in 1 : 1 Pyro Soda at 20° C.

$D_m = 5$; $1.57 D_m = 7.85$. $G_m = 2.71 \times 10^9$/sq. cm.

Fog = 0.30. $k = 3.6$ assumed.

$N \times 10^{-6}$	kN/G_m	$D/1.57\ D_m$	$D_{obs.}$	$D_{corrected\ for\ fog}$	$D_{calcd.}$
6.6	0.0087	0.0087	0.41	0.12	0.068
10.6	.014	.014	.46	.17	.11
16.6	.0216	.021	.53	.25	.17
26.4	.0354	.034	.65	.37	.27
52.8	.070	.065	.96	.70	.51
105.6	.140	.12	1.44	1.21	.94
211.0	.280	.21	2.14	1.96	1.65
422.0	.560	.35	3.00	2.87	2.75
660.0	.875	.45	3.57	3.48	3.53
1060.0	1.41	.53	4.15	4.10	4.16
1660.0	2.20	.60	4.62	4.60	4.71
2640.0	3.50	.63	4.83	4.82	4.95
4200.0	5.58	.636	4.93	4.93	5.00

FIG. 1.

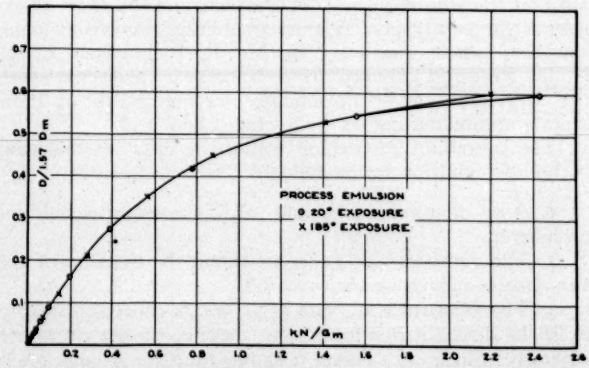


emulsion. This relation seems to hold at room temperature for various emulsions, provided there is complete penetration by the α-rays, but lowering the temperature apparently reduces the value of k (from 10 to 3.6 in the cases reported in Tables I and II).

This is not to be accounted for on the basis of a reduction of range but in the number of grains in the track made developable. For purposes of calculation this is equivalent to a reduction of the area of the cylinder of action. A fuller discussion of this will be given below.

These relative values of k are confirmed by an examination of cross sections of some films exposed at room and liquid-air temperatures, respectively, where the densities are low enough to allow examination of individual tracks. Then it was found that, although the ranges are approximately the same for full development (as would be expected), the number of grains in a track is approximately two and one-half times greater in the former than in the latter. In the case of short development times, the tracks are also reduced in length.

FIG. 2.



It may be of considerable help to anyone trying to use the new calculations if a graph is made of $D/1.57\ D_m$ vs. kN/G_m, which saves an enormous amount of time in calculation. It is apparent that the fraction of the maximum density can

be read off from this graph if k/G_m is known. This latter quantity for room temperature and process emulsions seems to be equal to the average projected area of the grains (see Fig. 2). This curve appears to be approximately the same at both temperatures measured and for both process and panchromatic emulsions.

Coarse-grained Panchromatic Emulsion.—If the Kinoshita formula is assumed to apply for this emulsion and the exponential "constant" is calculated by means of equation (1), it is found, as said above, that c_1 is not a constant; neither does it fall off regularly from a maximum initial value, as was the case in the Process emulsion, but it first rises to a maximum at $N = 5 \times 10^7$ and then falls off, as did c_1 for the fine-grained Process emulsion. This suggests, what is actually the case, that the Portrait Panchromatic is a double-coated emulsion and that the size-frequency distribution of the grains in the two layers is quite different.

Since the Kinoshita equation is so obviously inadequate for this emulsion, we will consider the application of equations (3) and (6). We are handicapped by not having separate data on the size-frequency distributions and the exact thickness of the two layers. The average grain-size of this emulsion as a whole was found by Mr. R. P. Loveland of the Kodak Research Laboratories to be 0.611 μ^2 (projected area), the large-grain layer presumably having grains of cross section approximating on the average about 1 μ^2.

The procedure adopted in fitting the data for this panchromatic emulsion was as follows:

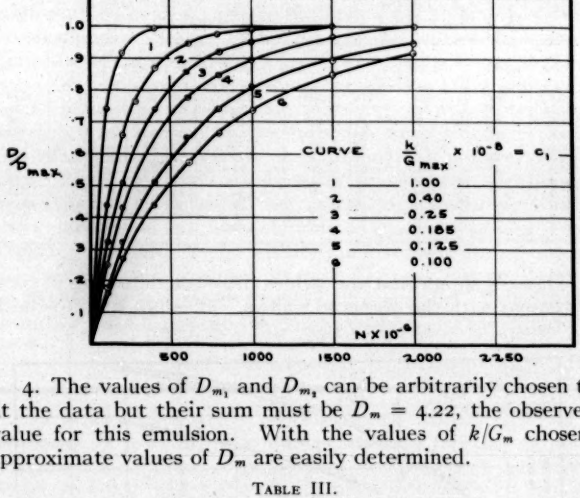
1. A set of equations (3) and (6) was assumed to hold for each layer.

2. The densities (as observed) should be the sum of the two densities given by (6a) and (6b).

3. The values of k_1/G_{m_1} and k_2/G_{m_2} can be chosen arbitrarily to fit the data but it is found that these constants are rather narrowly restricted. Figure 3 shows that, for a large grain emulsion ($k_1/G_{m_1} = c_1$ large), the photographic density ratio, D/D_m, rises toward unity much more rapidly than it does for a fine-grained emulsion (c_1 small). A study of these curves indicates that a k_1/G_{m_1} of approximately 0.90×10^{-8} is needed to

give the large density increases for the smaller values of N and that this must be combined with a k_2/G_{m_2} of approximately 0.1×10^{-8} to give the increase in density from 3.93 to 4.17, as N increases from 2×10^9 to 5.3×10^9. (See Table III.)

FIG. 3.



4. The values of D_{m_1} and D_{m_2} can be arbitrarily chosen to fit the data but their sum must be $D_m = 4.22$, the observed value for this emulsion. With the values of k/G_m chosen, approximate values of D_m are easily determined.

TABLE III.

Panchromatic Emulsion, 20° C.

$k_1/G_{m_1} = 0.90 \times 10^{-8}$. $k_2/G_{m_2} = 0.1 \times 10^{-8}$.

$D_{m_1} = 1.45$; $1.57 D_{m_1} = 2.28$. $D_{m_2} = 2.77$; $1.57 D_{m_2} = 4.35$.

$D_m = D_{m_1} + D_{m_2} = 4.22$ Fog $= 0.50$.

$\pi r^2 = 0.611\mu^2$.*

$N \times 10^{-6}$	Nk_1/G_{m_1}	$D_1/1.57\ D_{m_1}$	D_1	Nk_2/G_{m_2}	$D_2/1.57\ D_{m_2}$	D_2	$D_{obs.}$	$D_{corrected\ for\ fog}$	D_1+D_2
10.6	0.095	0.089	0.20	0.011	0.011	0.05	0.64	0.16	0.25
16.6	.149	.125	.29	.017	.017	.07	.75	.28	.36
26.4	.238	.22	.50	.026	.025	.11	.93	.49	.61
52.8	.475	.31	.71	.053	.050	.22	1.36	.98	.93
106.0	.954	.46	1.05	.106	.100	.44	1.85	1.53	1.49
211.0	1.90	.58	1.32	.211	.170	.74	2.36	2.11	2.06
422.0	3.80	.62	1.41	.422	.290	1.26	2.87	2.69	2.67
848.0	7.60	.63	1.43	.85	.440	1.90	3.38	3.27	3.33
1323.0	11.90	.635	1.45	1.32	.520	2.26	3.72	3.65	3.71
2010.0	18.10	.636	1.45	2.01	.580	2.52	3.96	3.93	3.97

* Microscopically determined.

Tables III and IV show for 20° C. and for − 185° C. the calculated values of D_1, D_2, and D, using two sets of equations (3) and (6) and the values of k_1/G_{m_1} and D_m, etc., given at the head of each table.

TABLE IV.

Portrait Panchromatic Emulsion, − 185° C.

$k_1/G_{m_1} = 0.80 \times 10^{-8}$. $k_2/G_{m_2} = 0.075 \times 10^{-8}$.

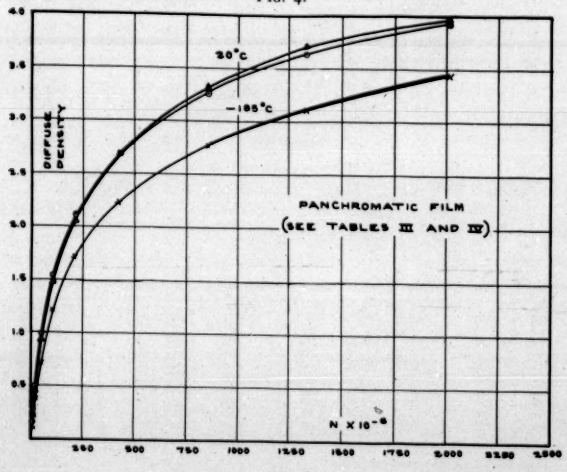
$D_{m_1} = 1.30$; $1.57 D_{m_1} = 2.04$. $D_{m_2} = 2.55$; $1.57 D_{m_2} = 4.0$.

$D_m = D_{m_1} + D_{m_2} = 3.85$. Fog = 0.47.

$N \times 10^{-8}$	k_1N/G_{m_1}	$D_1/1.57\ D_{m_1}$	D_1	k_2N/G_{m_2}	$D_2/1.57\ D_{m_2}$	D_2	$D_{obs.}$	$D_{corrected\ for\ fog}$	D_1+D_2
10.6	0.085	0.08	0.16	0.008	0.008	0.03	0.56	0.10	0.19
16.6	.133	.12	.25	.012	.012	.05	.66	.21	.30
26.4	.211	.18	.37	.020	.02	.08	.80	.37	.45
52.8	.422	.29	.59	.04	.036	.14	1.10	.71	.73
106.0	.85	.44	.90	.08	.075	.30	1.54	1.21	1.20
212.0	1.70	.56	1.14	.16	.14	.56	2.00	1.72	1.70
424.0	3.39	.62	1.27	.32	.24	.96	2.46	2.24	2.23
848.0	6.78	.63	1.28	.635	.374	1.50	2.93	2.77	2.78
1323.0	10.6	.64	1.29	.99	.46	1.84	3.24	3.12	3.13
2010.0	16.1	.64	1.30	1.51	.54	2.16	3.53	3.45	3.46
3360.0	27.0	.64	1.30	2.52	.60	2.40	3.75	3.69	3.70
5280.0	42.0	.64	1.30	3.95	.625	2.50	3.91	3.87	3.80

Figure 4 shows that the values thus calculated are in good agreement with the observed values. It is not easy to check

FIG. 4.



the average grain size, for although the theory of a single-coated emulsion indicated that k/G_m was approximately equal to the average projected area of the grain, it is difficult to apply this to a double-coated emulsion when the uncollimated α-rays mostly pass through the first emulsion and only partially through the second. The fact that k_1/G_{m_1} comes out to be 0.9×10^{-8}, about the value to be expected for the large-grained coating, and k_2/G_{m_2} comes out to be 0.1×10^{-8}, a value smaller than what would be expected for the average grain size of the fine-grained process emulsion, seems to check with the fact that the coarse coating is the upper one. The value of k_2/G_{m_2} can, however, not be identified with the average cross section of the grains in the lower layer, since the value of G_{m_2} appropriate to the analysis is uncertain for non-collimated α-rays, unless the rays have a sufficient penetration to use up all the grains in the emulsion. But the value of k_2/G_{m_2} is as it should be, smaller than that to be expected for complete penetration of the lower layer.

Table IV and Figure 4 give the data for this emulsion at $-185°$ C. and indicate that, with allowance for a temperature variation of k/G_m as in the Process emulsion, the equations fit the data with great exactness.

EXPERIMENTAL PROCEDURE AND RESULTS.

In order to study the effect of temperature variation, in our case, of lowering the temperature, on the photographic action on α-particles, it is necessary to provide a light-tight sensitometer in which the film or plate can easily be brought to and maintained at the desired temperature, and at the same time in which both time and intensity of α-particle exposure may be varied.

The Sensitometer and Its Operation.—It was at first thought that it would be possible to construct a sensitometer using an adaptation of the vacuum chamber principle employed by Wilkins and Wolfe.[5] In that way, practically a collimated beam of α-particles would reach the film or plate from the source, and by reducing the pressure in the chamber to less than a millimeter of mercury, there would be no danger of fluorescence, provided the film or plate would be in contact with the window of the chamber. Also, a lack of evenness of the deposit of polonium source would not be detrimental.

It was found, however, that while the system worked well enough at room temperature, it was very difficult if not impossible to maintain a vacuum in the source chamber when the temperature was lowered to that of liquid air. The difficulty was that the very thin mica "window" (about 5 μ thick) had to be attached to the metal chamber with some kind of cement and no cement was found which would not harden and crack loose with alternate lowering and raising of the temperature over the range from that of the room to that of liquid air. After two or three alternations, the window would break loose completely. No clamp of sufficient strength to hold the window on could be used, since this would separate the window from the film by an amount of air thick enough to alter the range of α-particles at different temperatures to an appreciable degree.

It was finally decided to use a source, or as it turned out later, two sources, very nearly but not quite in contact with the photographic film. At 0.1 mm. distance, errors due to fluorescence and to change of range of α-particles, caused by the increase of density of the thin layer of air between the film and the source with lowering of the temperature to $-$ 185° C., are not sufficiently great to be of importance.

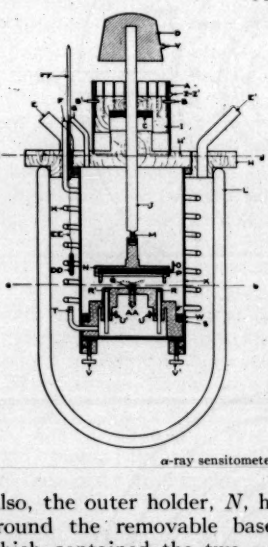
As to the former source of error, Wilkins and Wolfe [5] have found that fluorescence is at a maximum in a thickness of air of from 3 to 4 cm. for polonium α-rays, and it would be exceedingly small for such a thin layer as 0.1 mm. A test, using a thin piece of quartz between the film and the source in the normal position of the film, was made, exposing for 16 hrs. It showed no developed image. This indicated that there was not sufficient fluorescence, if any, to affect the film within the limits of the exposure.

As to the latter source of error, the 0.1 mm. of air at $-$ 185° C. is equivalent to about 0.18 mm. at room temperature, which should decrease the range of the α-particles by a little over 4 per cent., which, in terms of range of α-rays, would be an average of less than half a grain per track.

Figures 5*A* and 5*B* show vertical and horizontal cross-sectional sketches of the α-ray sensitometer. The film was placed face outward in a copper holder, *O*, which in turn was slid into the heavier holder, *N*, connected by a universal

joint, M, to the hard rubber rod, U, which could be slid up and down through the top of the sensitometer, which was made light-tight by having a cap, I, fastened securely to the rod, a raised portion of the inner top, and a slotted bakelite cylinder, A, surrounding the cap serving as the light-lock.

FIG. 5A.

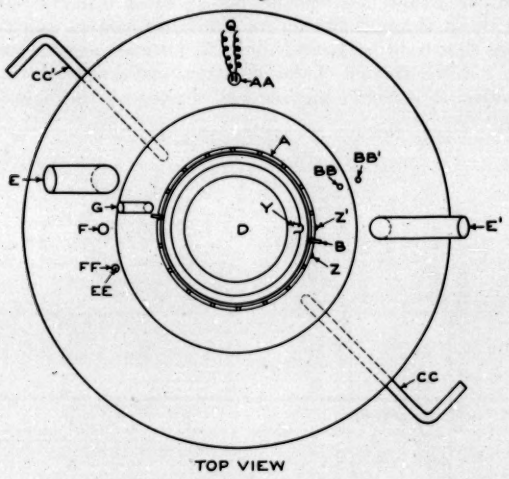


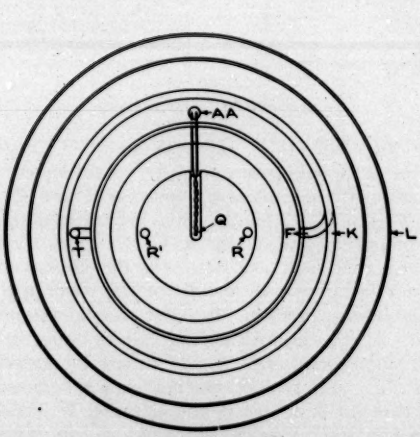
LEGEND :—
A-SLOTTED CYLINDER TO CONTROL POSITION OF FILM.
B-B'-PINS TO SLIP INTO SLOTS IN 'A' CONTROLLING POSITION OF FILM.
C-COTTON.
D-HANDLE FOR FILM HOLDER.
E-E'-AIR OUTLET FROM THERMOS JAR.
F-AIR INLET TO SENSITOMETER.
G-AIR OUTLET FROM SENSITOMETER.
H-OUTER STATIONARY TOP.
I-INNER REMOVABLE TOP.
J-LIGHT-LOCK COVER.
J'-HARD RUBBER ROD FOR RAISING, LOWERING AND TURNING FILM HOLDER.
K-COPPER COIL FOR COOLING AIR
L-THERMOS JAR.
M-UNIVERSAL JOINT.
N-FILM SHEATH HOLDER.
O-FILM SHEATH.
P-FILM.
Q-THERMOCOUPLE.
R-R'-SOURCES.
S-LEAD GASKET.
T-PLUGGED VACUUM CONNECTION.
U-U'-SET SCREWS FOR CONTROLLING POSITION OF SOURCES.
V-V'-SCREWS FOR TIGHTENING BOTTOM AND PLATFORM OF SENSITOMETER IN PLACE
W-FLANGE SCREWED AND SOLDERED TO WALL OF SENSITOMETER.
X-BRASS WALL OF SENSITOMETER.
Y-GUIDE KNOB ON HANDLE.
Z-Z'-GUIDE KNOB ON SLOTTED CYLINDER.
AA-OUTLET FOR LEAD WIRES TO THERMOCOUPLE.
BB-BB'-GUIDE KNOBS FOR INNER TOP.
CC-CC'-PINS TO FIX POSITION OF INNER TOP. (SEE TOP VIEW)
DD-PARAFFINED CORK FLOAT.
EE-COPPER WIRE AS INDICATOR ATTACHED TO FLOAT.
FF-GLASS TUBE IN WHICH EE MOVES UP OR DOWN.
a-b-UPPER PLANE OF LOWER CROSS SECTION VIEW.
c-d-LOWER PLANE OF TOP VIEW.

α-ray sensitometer, vertical cross section.

Also, the outer holder, N, had a sleeve which slipped down around the removable base of the sensitometer chamber which contained the two α-ray sources, R and R', held in place by set screws. This base was originally designed as a vacuum chamber, and hence it had a more complicated construction than was necessary for the later work. The tube, T, for instance, was meant for the vacuum tube connection but was sealed off. In order to hold the removable base tightly in place and without leakage of liquid air into the inside of the sensitometer, it was forced by means of the screws, V, V', and two others not shown, against a lead gasket between a flange on it and the ring, W, screwed and soldered to the brass cylinder, X. The top of the sensitometer

FIG. 5B.





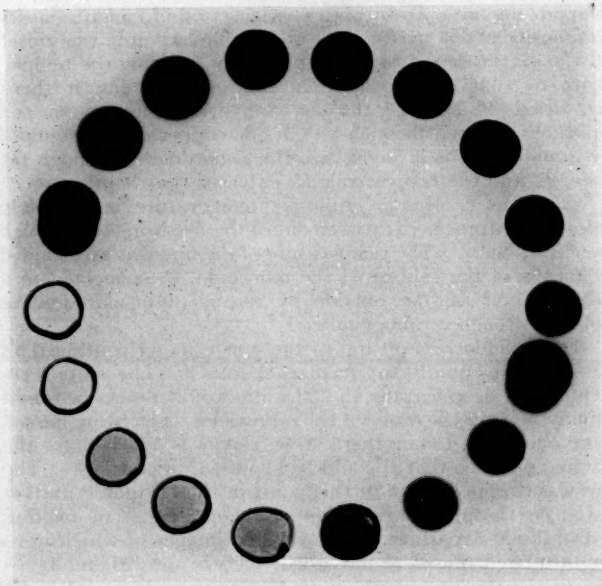
α-ray sensitometer, horizontal cross sections.

was turned out of wood which was then soaked in hot paraffin. It was made in two parts, an outer ring holding the brass cylindrical chamber and the inner portion which fitted into it, and which held the film holder and its connections. The chamber of the sensitometer was placed in a one-gallon thermos jar, *L*, in order to be able to lower the temperature of the film to that of liquid air. Tube *H* was connected to the liquid-air supply and tube *E* provided an exit for the evaporating air. To prevent condensation of moisture inside the sensitometer, particularly on the film when it was raised off the platform and to assist in quickly lowering the temperature to that of the liquid air and maintaining it there, air, dried by passage through anhydrous magnesium perchlorate and then through an outside copper coil surrounded by liquid air, was brought into the sensitometer through the tube, *F*, and the copper coil, *K*, entering the chamber at *F'*. It was thus cooled to liquid-air temperature immediately before its entrance. It passed out of the sensitometer through the exit tube, *G*. The temperature of the film was ascertained by means of the calibrated thermocouple, *Q*, connected to a galvanometer on the outside by means of insulated wires passing through a rubber tube, *Y*.

The cylinder, *A*, on top of the sensitometer contained 18 slots spaced equidistant from each other. The slots were about 5 cm. deep in order that the film would always be raised quickly beyond the range of the α-particles when being moved from one part to another. One slot was marked as the starting point so that it could be identified in the dark. The film was dropped down at this point in the beginning until it rested on the platform containing the sources, thus making two untimed exposures, the developed images of which were not measured but were discarded. There were therefore 16 measured exposures, eight with the weak source and eight with the strong (see the reproduction of a typical series of exposures, Fig. 6, ranging in times, ordinarily, from 1/2 minute to 1/2 hour). It was necessary to rest the film on the platform at the beginning in order that it could be brought rapidly to the desired low temperature. The time required for the film to reach equilibrium at $-185°$ C. was about a half hour. The consumption of liquid air for a complete run amounted

to between 3 and 4 liters. In order to know how much liquid air was in the thermos jar, and not have the liquid air overflow and be wasted, a float with an indicator was used. The copper wire indicator was enclosed in a glass tube to prevent condensation of moisture from hindering its freedom of motion up and down.

FIG. 6.



When it was desired to make exposures at − 80° C., the thermos jar was about two-thirds filled with a soft mush of solid carbon dioxide and acetone—after first placing a film in the sensitometer and passing dry air through the interior for 10 minutes to remove the moist air.

Preparation of Polonium Sources.—Polonium is the best source of pure α-radiation and is quite easy to prepare in a

form suitable for photographic work. The polonium was secured from old radon needles by a procedure similar to that described by I. Curie.[7] A quantity of needles sufficient to give approximately 2 cc. of powdered glass was ground in a mortar. The powder was placed in a crucible and warmed almost to redness. When cool, it was covered with 5 cc. of concentrated hydrochloric acid solution. This was warmed and allowed to stand for several days. Silver foil was then placed in the solution overnight. The foil disintegrated slightly but not enough to prevent it from being removed from the hydrochloric acid solution. It was removed and dissolved in 0.22 *N* nitric acid. The solution was evaporated just to dryness over a steam bath and the residue treated with 0.096 *N* hydrochloric acid. The resulting solution contained radium E and radium F (i.e., polonium) comparatively free from impurities.

The sources finally used were prepared by rotating in this solution silver disks, 0.5 cm. in diameter and 0.3 cm. thick, and highly polished on one of the flat surfaces. The other side of the disk was bored and tapped to screw in a brass rod. The sides of the disk and lower portion of the brass rod were painted with cellulose acetate lacquer to prevent deposition there. Only radium E and polonium are deposited on a polished silver surface from such a solution. The small amount of radium E decays within a few days leaving only polonium which has a half-life period of 140 days.

A preliminary source was made and tested photographically, and with an electroscope, in order to determine the correct concentration of the polonium solution and time of plating required to obtain a just perceptible developed image on the film with a quarter-minute exposure with the source 0.1 mm. from the surface of the film. The time and concentration of the polonium solution required for the strong source were estimated from this. The final sources were made by rotating the silver disks (screwed on the end of brass rods) for 10 minutes in the following solutions:

[7] Curie, Irene: *J. chim. phys.*, **22**, 471–87 (1925). Curie, Irene, and Joliot, F.: *Ibid.*, **28**, 201 (1931).

For the weak source: 1 cc. of a dilute solution (prepared by diluting 1 cc. stock solution to 10 cc. with water) and 9 cc. water.
For the strong source: 4 cc. stock solution, and 6 cc. water.

A weak source was prepared as stated above and was given an extremely thin covering of silver by the evaporation method of producing metallic mirrors, worked out by Dr. Brian O'Brien and Dr. T. A. Russell of the Institute of Applied Optics of the University of Rochester, with the idea of giving the polonium a protective coating. Upon testing and finding that the coating caused little if any loss in α-radiation, and that it did offer a substantial protection to the very delicate polonium deposit, the two final sources used in the sensitometer were coated with silver in the same way.

Correction of Exposure for Decay of Polonium.—Since all the exposures in this entire work could not be made in one day but were actually made over a period of several months, it was necessary to correct each exposure made, after the first one or two, for the decay of the polonium. This was done by means of the equation: [8]

$$\frac{N}{N_0} = e^{-\lambda t},$$

where N = rate of emission of α-particles at any expired time t; N_0 = rate of emission of α-particles at the initial time; λ = the transformation constant, which for polonium is 4.95×10^{-3} day^{-1} $= \frac{.693}{T}$, where T is the half-life, 140 days.

$$\log_e \frac{N_0}{N} = \lambda t = \frac{.693}{T} t.$$

Converting this to Briggsian logarithms, which are more convenient:

$$\log \frac{N_0}{N} = 0.00215t.$$

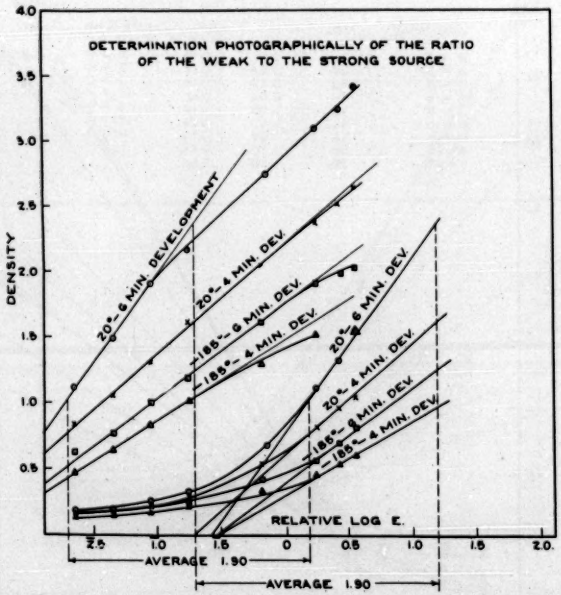
For each day after the first, 0.00215 times the number of days expired was subtracted from the log E values for the first day.

[8] Rutherford, E., Chadwick, J., and Ellis, C. D.: "Radiations from Radioactive Substances," Cambridge Univ. Press, London, p. 9, 1930.

It should be noted at this point that the decay constant of polonium and other radioactive substances is not affected by lowering their temperature to that of liquid air and even of liquid hydrogen.[9]

Relative Strength of the α-Ray Sources.—Eggert and Luft [2] state that "the same density is produced by the same number of α-particles per square centimeter of emulsion surface

FIG. 7.

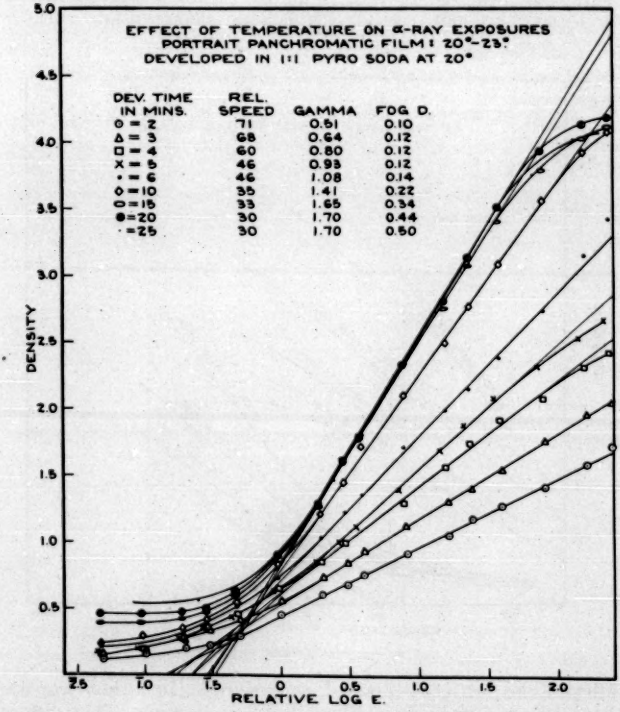


independent of the time of radiation." In other words, there is no reciprocity failure for α-radiation. They offer some experimental confirmation of this statement.

[9] Rutherford, E.: *Wien. Ber.*, 120, 303 (1911). Curie, M., and Onnes, H. Kamerlingh: *Phys. Lab. Leiden*, No. 135 (1913); *Akad. Wetensch. Amsterdam*, 15, 37 (1913); *Le Radium*, 10, 181 (1913).

Assuming it to be true, it was a simple matter to determine photographically the relative intensities of the two α-ray sources. A series of exposures was made with the two sources in the sensitometer (i.e., simultaneously) for times so arranged

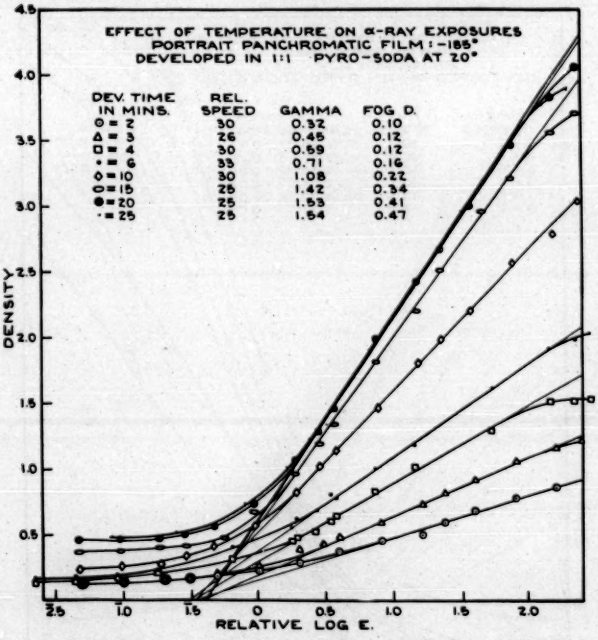
FIG. 8A.



as to give an overlap of the density-log E curve at the longest exposures with the weak source, with that at the shortest exposures with the strong source, preliminary exposures having shown about how much density would be developed

in each case. The data were plotted and are shown in Figure 7. The group of curves above are those of the strong source, those below of the weak source, plotted so that the initial exposures are all on the same exposure ordinate.

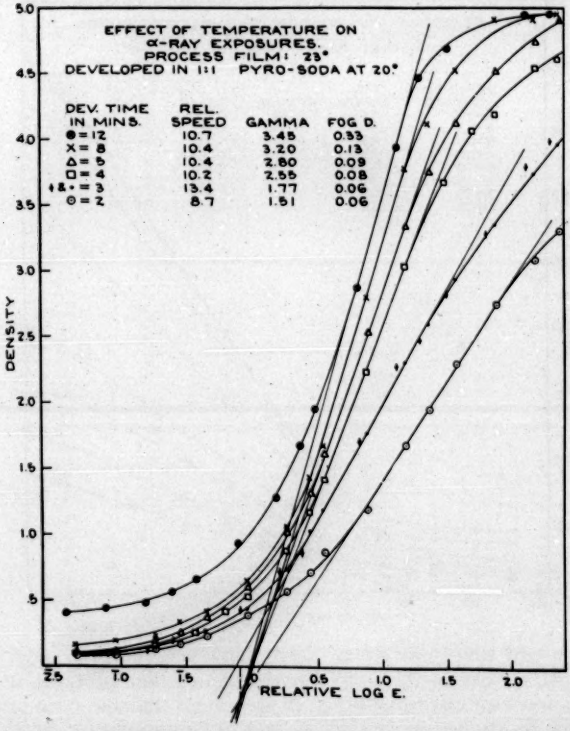
FIG. 8B.


EFFECT OF TEMPERATURE ON α-RAY EXPOSURES
PORTRAIT PANCHROMATIC FILM : -185°
DEVELOPED IN 1:1 PYRO-SODA AT 20°
DEV. TIME IN MINS. REL. SPEED GAMMA FOG D.
0 = 2 30 0.32 0.10
Δ = 3 26 0.45 0.12
□ = 4 30 0.59 0.12
• = 6 33 0.71 0.16
◊ = 10 30 1.08 0.22
○ = 15 25 1.42 0.34
● = 20 25 1.53 0.41
· = 25 25 1.54 0.47
DENSITY
RELATIVE LOG E.

From the difference in the log E units between any equal density points on the corresponding straight-line portions of low and high intensity curves, it was found that the ratio of weak to strong source was 1 : 79.4. This holds for both times of development and both temperatures at which exposures were made. Also, with this ratio of exposures all the sensitometric curves line up perfectly (Figs. 8 and 9, etc.).

To check this determination of the ratio, the rate at which α-particles were emitted from the two polonium sources used was determined by means of an ionization chamber and a

FIG. 9A.



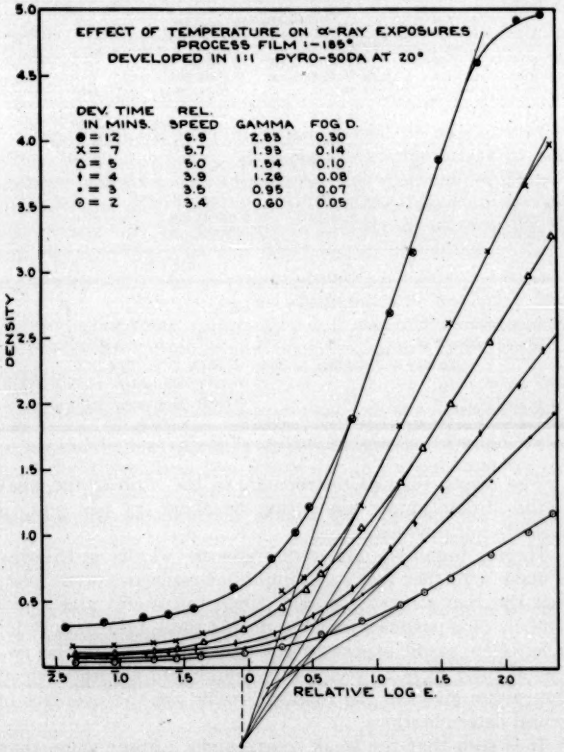
linear amplifier of the Wynn-Williams type.[10] With this amplifier, the ions produced when a single α-particle enters

[10] Williams, Wynn: *Proc. Roy. Soc.*, 131, 391 (1931).

the chamber causes an electrical impulse which is amplified sufficiently to trip a mechanical counter.

Within the limits of error, the counter recorded all the

FIG. 9B.



α-rays entering the chamber because, as can be seen in Table V, the same rate of emission for the strong source was found for different apertures, distances, and counting rates.

TABLE V.

Rate of Emission of α-Rays from the Polonium Sources.
June 14, 1934.

Counting Rate	Distance from Source to Aperture	Radius of Aperture	No. of α-Rays/cm.² of Source/min.
		Weak Source.	
15.6/min.	12.38 cm.	0.1651 cm.	1.25×10^6
13.0/min.	13.16 cm.	0.1651 cm.	1.18
16.2/min.	11.79 cm.	0.1651 cm.	1.18
		Average	1.20×10^6
		Strong Source.	
73.4/min.	45.53 cm.	0.1651 cm.	79.8×10^6
8.5/min.	45.59 cm.	0.05575 cm.	81.0
28.1/min.	25.10 cm.	0.05575 cm.	81.0
		Average	80.7×10^6

January 8, 1934.

Weak source ..... 2.60×10^6/cm.²/min.
Strong source ..... 175.0×10^6/cm.²/min.

Quantity of Polonium on Sources, January 8, 1934.

Weak source ..... 0.00117 equivalent millicuries/cm.²
Strong source ..... 0.0788 equivalent millicuries/cm.²
Ratio of weak to strong source (count method) = 1 : 67.2
Ratio of weak to strong source (photographically) = 1 : 79

The reason for this discrepancy in the ratio of the weak to the strong source amounting to about 15 per cent. is certainly not obvious.

Having found the above discrepancy, we deemed it wise to make a further test. A number of exposures were made with the two sources for such times, as would give equal numbers of α-particles radiated during the total exposure for each. One would expect to get equal densities in the two cases if there were no reciprocity failure and no other effect. The results given in the following table are the averages of several determinations.

It is seen that the weak source gives a lower value than the strong source by 0.03 to 0.07 in logarithmic units. That is, one value differs from the other by from 10 per cent. to 12 per cent., which is in substantial agreement with the previous method of determining the difference.

TABLE VI.

Unequal Photographic Effect of Equal Numbers of α-Particles with Weak and Strong Sources.

Source.	No. of α-Particles per cm.² per min.	Total No. α-Particles per cm.².	Time of Exposure in min.	Density.
Weak.....	1.20×10^6	40.3×10^6	33.6	0.74
Strong.....	80.7×10^6	40.3×10^6	0.5	0.77
Weak.....	1.20×10^6	80.7×10^6	67.2	1.27
Strong.....	80.7×10^6	80.7×10^6	1.0	1.34

Eggert and Luft [2] claimed that there is no reciprocity law failure with α-particles. A more exhaustive study of this question which has since been made by Wolfe and Wilkins [11] substantiates this claim and it has been shown that the discrepancy may be due partly to a latent-image growth with time between exposure and development and to some extent to the effect of recoil polonium atoms.

In the application of the mathematical analysis given above, the apparent reciprocity failure was taken into account, the curves for the weak and strong exposures being made to overlap.

SENSITOMETRIC DETERMINATION AT ROOM AND LOW TEMPERATURES.

Exposures were made for a series of times at room temperature and then a new film was placed in the sensitometer and brought to the temperature of liquid air. Later, a few experiments were carried out at the temperature of solid carbon dioxide. When the galvanometer indicated that equilibrium was reached at the low temperature, a series of exposures was made at that temperature.

There was condensation of moisture on the film when it was removed from the sensitometer but, according to some previous work of Sheppard and Wightman,[12] this should not affect the latent image, that is, if we assume that α-ray latent image and latent image produced by light behave essentially the same with respect to moisture, and there is no reason to expect a difference.

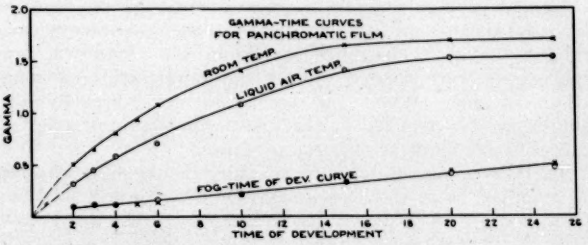
[11] Wolfe, R. N., and Wilkins, T. R.: *J. Optical Soc. Amer.*, **26**, 105–10 (1936).

[12] Sheppard, S. E., and Wightman, E. P.: *Ber. VIII. Intern. Kongress Phot.*, Dresden, 157–63 (1931).

Development of the film was carried out at 20° C. in 1 : 1 pyro-soda developer, as used previously in the work with light. The film exposed one afternoon was not developed until the next afternoon, so as more nearly to equalize the time between exposure and development for the two series and to give time for both films to be in approximate equilibrium with the air of the laboratory as to temperature and moisture content. Brush development was used to avoid irregularities as far as possible. The films were mixed, washed, and dried under carefully controlled conditions, these treatments being alike for all the films.

The densities were measured on a Capstaff-Purdy densitometer for the lower densities and on a Jones densitometer for the highest densities (the two densitometers were checked against each other) and plotted against the logarithm of the exposures, and the results are shown in Figures 8*A*, 8*B*, 9*A*, and 9*B* for Portrait Panchromatic and Process films at 20° (8*A*, 9*A*) and at − 181° C. to − 185° C. (liquid-air temperature, which will in future be called − 185° C.) (8*B*, 9*B*). These two kinds of film were used because the two types of emulsion on them had been employed previously in the case of the low-temperature work with light as the illuminant.

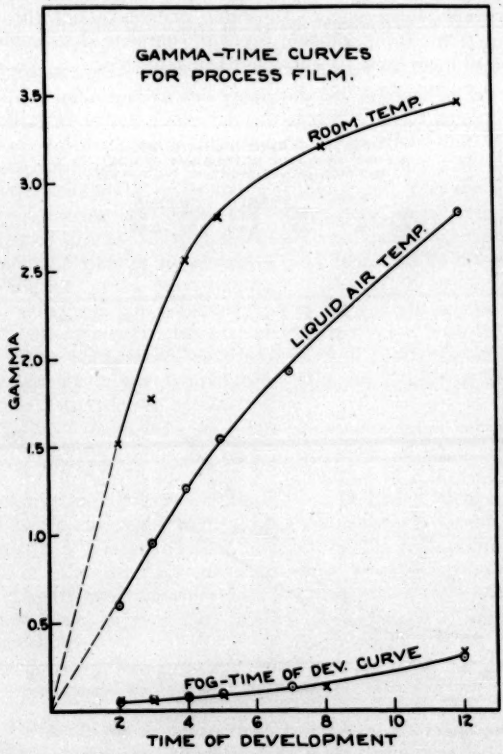
FIG. 10.



From the graphs, relative speed and contrast were determined and it can be seen that there is a difference of between 4 and 7 to 1 (depending on the development time) in the relative speed to α-rays between the panchromatic and the process films, and that for both there is a definite but com-

paratively small loss of speed with the lowering of temperature, even to − 185° C. At this low temperature, what loss there is (in the case of the panchromatic film) is greater for

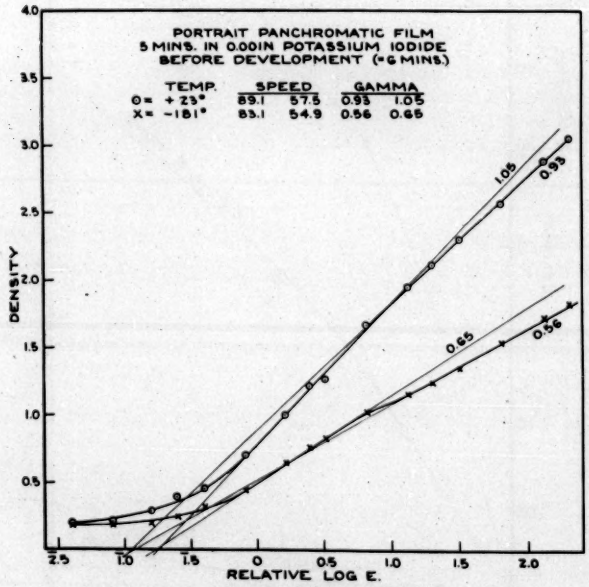
FIG. 11.



short than for long times of development. This ties in with other facts to be mentioned later. The contrast is also more affected for short than for long times of development and the

degree of effect is almost as great as with exposures to light. The effect on contrast at − 185° C. is more readily seen in Figures 10 and 11. In the early stages of development, the contrast of the film exposed at − 185° C. is about a half of that at room temperature. With increasing development, the proportion of the one to the other decreases, but the two curves never fully coincide even at complete development. We shall have more to say about this later.

FIG. 12.



The effect on speed and contrast at − 80° C. as far as could be determined from the rather meager results at that temperature (and not given in detail for that reason) is similar but less in amount than at − 185° C.

Some exposures were made at room temperature both

before and after lowering the film to liquid-air temperature and bringing it back again. The sensitometric curves in these cases were indistinguishable from each other and from the room temperature controls. *To produce the effect on contrast and on speed*, where there is any, *it is therefore necessary to expose the film while it is at the low temperature.* This is in agreement with the effect of temperature on light exposure.

Effect of Iodide Treatment.—Since α-particles pass through the silver halide grains and very probably produce an internal as well as an external effect, it was thought that it would be of interest to break open the grains after exposure but before development by treating them for a short time with dilute potassium iodide in order to see if this would alter the effect of temperature on speed and contrast as produced with untreated grains. The general effect on speed and contrast for a single time of development was found to be unaltered (see Fig. 12). The only difference in the results as compared with uniodized film, was the break in the straight-line portion of the characteristic curve which occurred with both the low and room temperature exposed film, and hence the effect is independent of the temperature, and practically so of the internal latent-image speck.

Effect of Desensitization.—The energy of a single α-particle is so great as compared with a quantum of light energy, that it can very likely cause the formation of a latent-image speck containing several hundred to a thousand silver atoms and hence can make each grain that it strikes developable. Hence, it is presumable that treating the film with permanganate or other strongly oxidizing agent would have no great effect on its speed for α-particles. The question arose whether or not it would be equally unaffected if exposed at very low temperature.

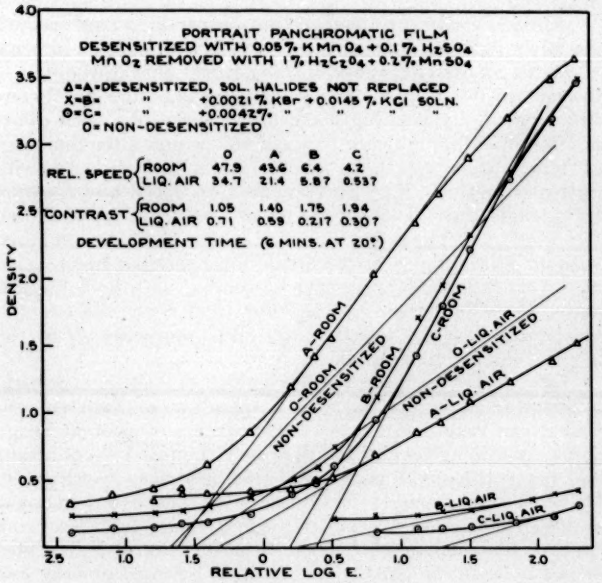
A Portrait Panchromatic film from the same lot as was used previously was treated as follows:

Treatment A.

1. Thirty minutes in 0.05 per cent. $KMnO_4 + H_2SO_4$; followed by
2. Five minutes rinse in 5 changes distilled H_2O; followed by
3. Fifteen minutes in 1 per cent. $H_2C_2O_4 + 0.2$ per cent. $MnSO_4$; followed by

4. Thirty minutes in running tap water;
5. Dried in a thermostat operated at 20° C. and 50 per cent. relative humidity;
6. Exposed to α-radiation the same day, and developed, etc., the following day.

FIG. 13.



Treatment B.

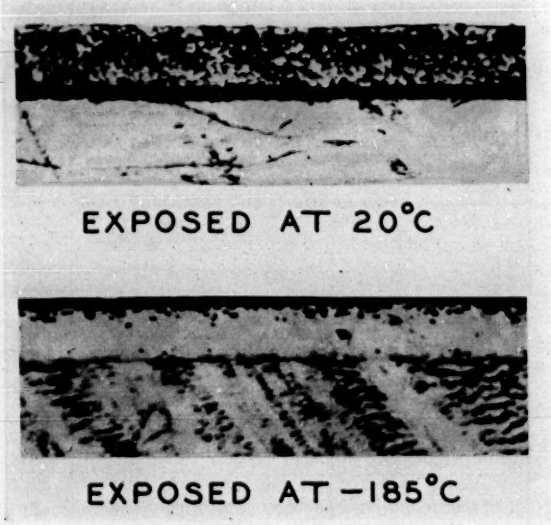
The same as (*A*) except that (4) consisted of bathing 5 minutes each in 6 changes of solution of soluble halides, consisting of 0.0021 per cent. KBr and 0.0145 per cent. KCl, in order to replace the soluble halides removed by the previous treatment. The solution was removed from the surface with filter paper and the film was dried in the thermostat as in *A*.

Treatment C.

The same as (*B*) except that the amount of soluble bromide used was doubled (to 0.0042 per cent.).

The results of this work are shown in Figure 13. As was expected relative speed at room temperature, as measured by

FIG. 14.



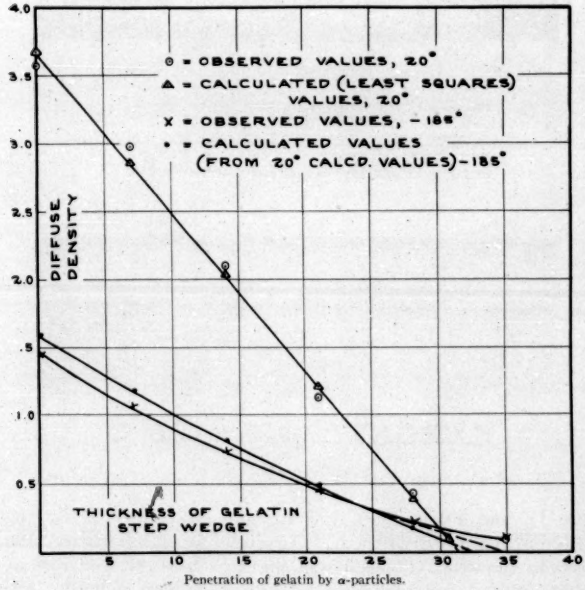
Cross sections of "desensitized" film exposed at two temperatures and processed alike.

the H. and D. method, was inappreciably affected by the "desensitizing" treatment. At liquid-air temperature, the loss in the relative speed was slight. However, contrast at room temperature which was somewhat increased by "desensitizing" was decreased by about the same amount at the low temperature. Replacing the soluble halides lowered room temperature speed markedly without much change in contrast, and the lowering was increased with increase of

soluble bromide added, as might be expected. The amount of bromide and chloride replaced (Treatment *B*) was that found by analysis to be present in a similar commercial film.

The effect of the replacement of soluble halides on the low-temperature speeds could not be estimated accurately with the data on hand, since there is not enough of the characteristic curve available for that purpose. The effect on contrast is also uncertain, although the loss in it and the relative speed (in the case of *C*) appears to be enormous with the curves as drawn.

FIG. 15.



Penetration of gelatin by α-particles.

The most interesting thing about this large "desensitizing" effect and replacement of the soluble halide is shown by the photomicrographic cross sections of some of the exposed spots (at 500 diameters) made for us by Mr. R.

Edwards of the Kodak Research Laboratories. In Figure 14 are the cross sections of two spots, treated, exposed, and developed alike except that one was at − 185° C. and the other at 20° C. when exposed. The exposure was the longest of those given, 1 hour, and development time, 6 minutes. The considerable difference in density in the two is quite apparently due almost entirely to the difference in depth in the emulsion to which the grains developed. We shall have more to say about this in the following section.

Penetration or Range of α-Particles.—Several previous investigators have determined the penetrating power or range of α-particles from a polonium source, in an ordinary photographic emulsion. The earlier literature of this subject has already been reviewed by Wilkins and Wolfe.[5] Mühlestein,[13] whose work they discuss, found a penetration of the α-particles (horizontally) into a commercial emulsion of 27.7 μ. Blau [14] reported a penetration value of 27 μ. Wilkins and Wolfe [5] found a penetration of 29 μ for the α-rays in Eastman Process emulsion. Eggert and Luft [2c] studying the relation of penetration to concentration of silver halide grains in the emulsion, found that the penetration ranged from 25 to 30 μ in one case, and 23 to 30 μ in another case, when the grain concentration ranged from 1 to 1/23. It also ranged between 25 and 30 μ for some regular commercial emulsions. These results are all in substantial agreement.

A question arose as to whether or not change of temperature, exposure time, and/or development time affect the range of the α-particles in the emulsion, or in gelatin. To help settle this question several experiments were undertaken.

1. A step wedge of gelatin was prepared from a very thin sheet of gelatin made for us by Dr. R. C. Houck of the Kodak Research Laboratories. Measurements by micrometer and by the interferometer method, using sodium light as a standard, showed it to be very close to 7 μ thick. Five strips of this, about 25 mm. long, and of width varying from about 4 to about 20 mm., were laid one on top of the other

[13] Mühlestein, E.: *Arch. sci. phys. nat.*, [5], 4, 38 (1922)—quoted from Eggert and Luft, see ref. 2 above.

[14] Blau, M.: *Sitzber. Akad. Wiss., Math. naturw. Klasse* (Abt. IIa), 139, 327 (1930). See also: Dessauer, F.: *Zehn Jahre Forschung auf dem physik.-medizin. Grenzgebiet*, Leipzig, S. 390 (1931)—quoted from Eggert and Luft, see ref. 2.

to form steps. A strip of 40 μ thick gelatin, 1.25 cm. wide, was laid over the tablet so as to cover one-half of each step, to insure that there would be no exposure of the film over this half of the source while the other parts were being exposed. The α-particles do not penetrate through 40 μ thickness of gelatin nor cause any photographic effect by fluorescence even with a considerable time of exposure. The whole tablet was attached, by moistening it at the edges and using a little pressure, to an α-ray source 2.5 cm. square, prepared by depositing polonium, by the method previously described, on the highly polished surface of a silver plate of that size laterally and about 3 mm. thick. This step wedge only survived a few lowerings of the temperature to that of liquid air, but those were sufficient for the purpose.

For making the exposures, this source with gelatin tablet attached was laid face up on the center of the platform in the sensitometer, and when ready, the photographic film in the holder (process film was used), was lowered on it and a 5-lb. lead weight was set on top of the central rod constituting the handle of the film-holder, so as to press the gelatin tablet as flat as possible to avoid unevennesses. Tests showed that this was essential to get evenness and sharpness of images. After 60 minutes' exposure, the film was raised, turned horizontally through an angle of 180°, and again lowered for another exposure—on the other half of the film—of 60 minutes at room temperature. Tests had shown that this half would remain blank if only the first exposure were given and would give, at room temperature, identical results, within the limits of experimental error, when the film was exposed on both halves of the film area. For the exposure at liquid air temperature it was necessary first to bring the film to that temperature by lowering it into place and leaving it there for about an hour. This was a little longer than the thermocouple indicated was necessary for equilibrium to be reached.

The film was now turned horizontally through an angle of 185° for an exposure on the other half at the liquid-air temperature. Of course, the exposure made during the period of bringing the film to the low temperature was discarded. The films were developed for 5 minutes in pyro-soda developer at 20° C. with brush development, as before with the sensitometric exposures.

The density data are given in Table VII.

TABLE VII.

Densities for Exposures Made through Gelatin Tablet.

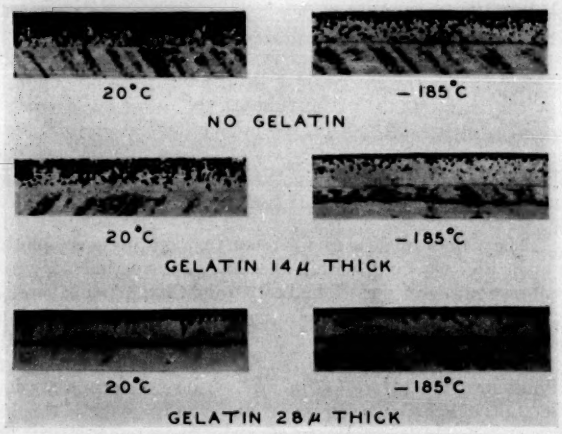
Thickness of Gelatin in μ	Densities for			
	20° detd.	20° corr.	−185° detd.	−185° calcd.
0	3.58	3.67	1.44	1.59
7	2.97	2.85	1.06	1.18
14	2.09	2.03	0.72	0.80
21	1.12	1.20	.44	.48
28	0.40	0.38	.19	.17
30.6	—	.07	—	—
35	0.07	—	0.08	—
Fog	0.08	—	0.07	—

The values of density for room temperature were plotted ($\odot$ in Fig. 15), and, within the limits of experimental error, fall on a straight line. The best straight line passing through the points was calculated by means of the method of least squares (3rd column above), resulting in the line through the points marked Δ, in Figure 15. The densities for exposure at liquid-air temperature ($\times$ in Fig. 15) do not form a straight line but a slightly curved one. The average slope of this line is considerably less than that for the room temperature, but much of the drop might be due to the loss of contrast previously noted. Using values of density taken from the calculated straight line (for room temperature) and the sensitometric curves, corresponding values of density for − 185° C. were found and when plotted gave the curve through the points marked $\bullet$, which lies only slightly above the curve through the observed values. The difference in the position of the two curves is probably within the limits of the experimental error.

The thickness of gelatin just sufficient to stop all the α-particles (i.e., the range) at room temperature, is seen to be about 30.6 μ, which is in good agreement with results of Eggert and Luft, who found a penetration of 30 μ for an emulsion with 1/23 its normal amount of silver halide grains. The range at liquid-air temperature is the same within the limits of error of the experiment.

Photomicrographs (at 500 diameters) of 1 μ thick cross sections of three exposure steps (every other one) on the films exposed at both room and liquid-air temperature (see Fig. 16)

FIG. 16.



Cross sections of films exposed through various thicknesses of gelatin.

show that at each temperature the depth to which the grains are developed—which is practically equivalent to the degree of penetration of the α-particles into the emulsion—varies (qualitatively) inversely as the thickness of gelatin interposed, and that the depth of penetration at the two temperatures, for corresponding gelatin thickness, is not greatly different, but that the number of grains per unit volume, developed in the case of the low-temperature exposure is definitely less than in the case of that at room temperature. These observations are from films developed 5 minutes. As will be seen below, these results would probably have been somewhat different if the film had been developed for 2 or some other small number of minutes.

2. To determine the range of α-particles in the emulsion at liquid-air temperature by the method of Mühlestein [13] was

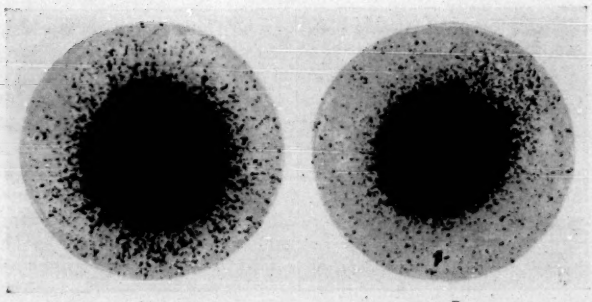
impractical, if not impossible, since it would have been necessary to put the specks of polonium in contact with the emulsion after lowering the temperature of the film, and since there is no liquid substitute for mercury (which becomes solid above that temperature), to hold the specks of polonium in close contact with the film.

In order to overcome these and other difficulties of that method, a new one was devised. A plug of silver, with the top cone-shaped and sharply pointed, was carefully made to fit in a correspondingly shaped opening near the center of a silver plate. The point of this cone passed through a tiny opening in the front of the plate. Upon lightly grinding and polishing the front of the plate, the top of the cone was flattened and polished. It was then taken out of the plate, and after lacquering all but the tip, the latter was plated with polonium as with the previous strong source, the lacquer removed with acetone and the plug put back into the plate and fastened in place. It thus formed a tiny source about 40 μ in diameter. By pressing film in close contact with this plate containing its minute source (i.e., by pressing down the film holder by placing on top of its handle a 5-lb. weight) it received an exposure similar to those made by dropping specks of polonium on the film and covering them with mercury, but somewhat larger in diameter. However, what we were interested in was not the absolute diameter (exclusive of that of the source) but the relative diameters at two temperatures.

A series of one-hour exposures on process film was made with this source both at room temperature and at that of liquid air, and the films were developed for a variety of times. It was found that the spots made at room temperature were all about the same size, that is, averaging about 125 μ diameter (the source is a circle of appreciable area as stated above, and is surrounded by a narrow circle of air between the source and the plate) when there was good contact (see Fig. 17*A*), and that the film exposed at liquid-air temperature gave smaller spots, that is, about 110 μ diameter, for short times of development (2 to 3 minutes—see Fig. 17*B*) but the same size as the room temperature ones (125 μ) for longer times of development (4 to 6 minutes). This result is not in disagreement with that in the previous section, where penetra-

tion of gelatin by α-particles was apparently the same at both low and room temperatures. There the development time was 6 minutes and here there was also no difference in penetrating power in the case of the 6 minutes' development time. It would appear that low temperature affects the rate of development of grains hit by low-energy α-particles, i.e., those which have passed through several grains.

FIG. 17.



A. B.

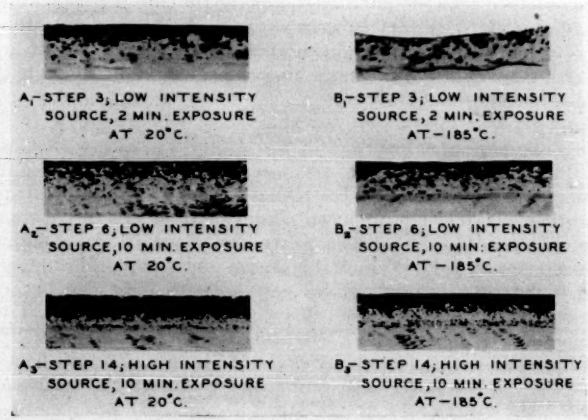
α-ray haloes.

A. Haloes exposed at both 20° and − 185°; all development times for 20° exposures, and 4–6 min. development for − 185° exposures. Average diameter = 125 μ.
B. Haloes exposed at − 185°; developed 2 min. only. Average diameter = 110 μ.

3. Photomicrographs at 500 diameters' magnification were made for us by Mr. R. Edwards of the Kodak Research Laboratories, of 1 μ thick cross sections of some of the developed spots on the films from which the sensitometric data (for 3 and 6 minutes' development time) were obtained. These gave important information as to an obscure point, that is, as to why the densities of low-temperature exposures were lower than the corresponding ones at room temperature. We show in Figures 18 A_1, A_2 and A_3, and B_1, B_2 and B_3, only a few of the photomicrographs from the panchromatic films. It can be plainly seen that there are fewer grains developed in the films exposed at the low temperature than in those at room temperature. This should be the case since there are fewer grains developed per track at the low tem-

perature, although the lengths of tracks are the same for longer development times. This applies at all exposures and to both times of development shown in the figures. This again may be to a certain extent a development effect, as it will be remembered from the gamma-time of development curves that the percentage lowering of contrast (gamma) is greater for short than for long times of development, and with

FIG. 18.


A_1–STEP 3; LOW INTENSITY SOURCE, 2 MIN. EXPOSURE AT 20°C.
B_1–STEP 3; LOW INTENSITY SOURCE, 2 MIN. EXPOSURE AT –185°C.
A_2–STEP 6; LOW INTENSITY SOURCE, 10 MIN. EXPOSURE AT 20°C.
B_2–STEP 6; LOW INTENSITY SOURCE, 10 MIN. EXPOSURE AT –185°C.
A_3–STEP 14; HIGH INTENSITY SOURCE, 10 MIN. EXPOSURE AT 20°C.
B_3–STEP 14; HIGH INTENSITY SOURCE, 10 MIN. EXPOSURE AT –185°C.

the panchromatic emulsion even 5 minutes' development is a comparatively short time.

Further, one can see in these and additional photomicrographs not shown that the average depth to which the grains are developed is less for a short (3 minutes) development time than for a longer (6 minutes) development time, and the nearer the surface of the emulsion, the greater the number of grains developed. These last two facts are, however, not unexpected since it takes time for the developer to penetrate, and on its way it dilutes itself by being used up, and in addition, produces reaction products which tend to restrain the development, more so on the inside than near the surface, where fresh developer is

replacing that used up and where the reaction products are to a greater or less extent being carried away.

4. The number of grains in a track was determined roughly by examining microscopically very low exposure spots on Process film developed for 3 minutes, which spots showed no visual increase in density above fog. In the film exposed at room temperature, there were from 10 to 15 grains per track. Only those tracks which did not penetrate at too sharp an angle into the emulsion could be counted satisfactorily. In the film exposed at liquid air temperature (the corresponding exposure step), the tracks were not only shorter but contained only from three to six grains and those for the most part lay further apart in the track, making the tracks more difficult to pick out and be certain of.

DISCUSSION AND INTERPRETATION.

In the previous paper in this series, by Sheppard, Wightman, and Quirk,[1] it was shown that lowering the temperature to that of liquid air produced a considerable loss of contrast and a very large but not complete loss of sensitivity to light. In a paper by J. H. Webb [15] it is shown how a part, if not most, of such a loss in contrast for exposures to light can be accounted for on the basis of reciprocity law failure. The exposures in the Sheppard, Wightman, and Quirk experiments were made with an intensity scale of illumination and hence part of the loss in contrast probably was due to the failure of this law. In the present work with α-rays there was a similar loss in contrast, yet here, in spite of the fact that there is an *apparent* reciprocity law failure, the loss in contrast cannot be ascribed to it since the exposure scale is divided into two halves and each half is on a time basis, yet the loss in contrast appears in each half without relation to the other.

It seems apparent, however, from the photomicrographic cross sections of the sensitometric steps and the photomicrographs of the "haloes," and from the gamma-time of development curves, that some of the loss is due to slowing down of development in its early stages.

Of course, this is not the ultimate cause. Sheppard, Wightman, and Quirk ascribed part of the loss in sensitivity

[15] Webb, J. H.: *J. Optical Soc. Amer.*, **25**, 4–23 (1935).

and contrast (for light exposures) at low temperatures to an immobility of the bromine set free by the exposure, whereas at room temperature it is dispersed and absorbed by surrounding agents at the instant of exposure or immediately thereafter. The immobile bromine, as the temperature rises after exposure, could and probably does attack the latent image, having no light action to restrain it from doing so.

This attack by bromine on the latent-image specks is probably what causes the difference in development rate, which is lessened in the earlier stages of development for both light and α-ray exposures at low temperature. It probably does not completely destroy all the latent-image specks but so decreases their size and number as to affect the initial development rate.

It is true that in the case of the exposure by α-particles a greater amount of bromine is liberated than with light and one might use this as an argument for claiming that one should, therefore, expect a similar even greater apparent lowering of sensitivity. But if more bromine is liberated by the α-rays, so also is more silver set free, thus making larger latent-image specks, and while they may be attacked after low-temperature exposure by more bromine, more of the latter is also probably at the same time absorbed by the surroundings (gelatin and other absorbents), and the net result is probably that a larger latent-image speck remains after exposure with α-rays at low temperature than with light.

Sheppard, Wightman, and Quirk also discussed and pointed out a certain similarity between the temperature photoconductance effect in silver halides and the photographic effect with light. We know nothing, however, concerning the photoconductance effect produced by α-particles in silver halides and its relation to temperature.

As we showed above, the process film differed somewhat in speed from the panchromatic film (the latter was about 4 to 7 times the α-ray speed of the former at the same temperature). The difference, as a matter of fact, is about the same as for white light exposure. There are two causes for this: (1) The number of grains under one sq. cm. in the panchromatic film is more than twice that in the process film. (2) The average grain size in the former is more than twice that in the latter.

Speed in the case of α-particles depends principally upon the size and number of grains of silver halide per unit area of film, assuming constant development conditions, and not at all upon preëxisting sensitivity specks in the grains as with light.

The effect of temperature on speed in the case of the panchromatic and of the process film is relatively the same.

Our experiments have shown that in the exposures with α-rays there were no detectable complications from secondary radiations in the visible or near ultra-violet regions which could play a part in the effects which we have recorded. Of course, it is possible that some secondary very short wave-length radiation is playing a part, such as the characteristic x-rays resulting on α-ray bombardment, but the effect of this radiation has not been noticeable.

For the astonishing effect produced by replacing soluble halides after oxidizing treatment on the sensitivity and contrast, of films α-ray exposed at low temperature, we at present have no satisfactory explanation. It seems unbelievable that the re-addition of so small a quantity of soluble bromide should have so great a "desensitizing" effect, and also very unlikely that it is largely an effect of restraint of development. Yet the photomicrographs show that even for the highest exposure given, at the low temperature only the very surface grains of the film were made developable.

SUMMARY AND CONCLUSIONS.

1. (*a*) The Kinoshita exponential equation for the relation of the density of the developed film to exposure to α-rays has been found not to apply for a diffuse source of the α-radiation either for a process or a double-coated panchromatic emulsion. But it has been found possible to fit the experimental data with a combination of two somewhat similar expressions, namely, (1) $G = G_m(1 - e^{-k(N/G_m)})$, in which G and G_m are, respectively, the number of grains already hit and the total number under unit area of emulsion surface, and N is the number of α-rays falling on that unit area during the time of exposure, and (2) $D = 1.57D_m(1 - e^{-G/G_m})$, in which D and D_m are, respectively, any density (corrected for fog) and the maximum density for complete exposure and infinite

development time. (*b*) At room temperature with complete penetration of the emulsion by the α-rays, k/G_m is approximately equal to the projective area of the average sized grain. At $-185°$ C. the value of k/G_m is less than this. (*c*) The relationship of D/D_m to N (at room temperature) has been shown graphically for various values of k/G_m. The larger k/G_m, the steeper is the initial rise in the curve. (*d*) With a double-coated emulsion, the equations are applied to each coating separately and the corresponding calculated D's are added. The relative thickness of the upper and lower layer in the panchromatic emulsion was not known, but, assuming the two layers to be approximately equal, the resulting composite theoretical curve fits the experimental data surprisingly well, and the size of k/G_m was of the right order of magnitude for each layer.

2. It has been shown that at room temperature α-rays produce about the same relative effect as light on the process and on the panchromatic emulsion examined, with respect to each other, and that when the exposure to α-rays is made when the temperature is very low, there is a loss in contrast similar to that found with light (using an intensity scale), but that this loss cannot be attributed either entirely or even in part to a reciprocity law failure. There is considerably less loss in speed, however, than there was with light.

3. An apparent reciprocity law failure was found for α-particles. This has recently been investigated much more thoroughly by one of us (Wolfe).

4. Photomicrographic studies reveal that for the same exposure there are fewer grains developed when exposure is made at low than at ordinary room temperature and that the rate of development in the earlier stages is less for the emulsion exposed at low temperature. This last is also shown in the gamma-time of development curves.

5. An enormous effect on sensitivity and contrast, caused by exposing at low temperature, films given oxidation treatment followed by replacement of the soluble halides removed by the said treatment has not been explained.

6. The hypothesis previously proposed, that at least part of the loss in contrast, and of speed, where there is such loss, by exposure at low temperature, is caused by the immobility

and non-absorption at the time of the exposure of the bromine set free by the exposure, which, as the temperature rises, later allows this bromine to attack the latent image, appears to hold for these experiments as it did for those with light exposure.

7. It should be stressed that for investigations with α-particles and other similar radiations, especially with diffuse sources, the process emulsion is much more suitable than others containing flat grains since the number of complicating factors is at a minimum.

ACKNOWLEDGMENT.

We wish to acknowledge our indebtedness to Messrs. R. F. Quirk and E. Huberth of the Kodak Research Laboratories, who developed most of the film for us, especially the sensitometrically exposed film, to Mr. V. Conley, of the University of Rochester, for help in preparing the metallic surfaces, and to others specifically mentioned in the course of this paper, who assisted in one way or another as mentioned there.

October 1, 1935,
ROCHESTER, N. Y.

FLIGHT ON ROTATING WINGS.*

BY

W. LAURENCE LePAGE,

Day & Zimmermann, Inc., Philadelphia, Pa.

(*Concluded from page 288.*)

(c) Inefficient Utilization of Power.

The question of power relates itself closely with the matter of disc loading. Most helicopter designs to date have involved heavy power losses by reason of complicated rotor systems with elaborate power transmission gears and shafts. Even the single rotor system, with individual blade propulsion, as in the Curtiss-Bleecker and Isacco designs, involves a loss of from 35 to 40 per cent. of available power in the aerodynamic inefficiencies of the individual propellers driving the rotor. This does not include the additional parasite drag losses due to the individual engines or gearing.

To date, most helicopter designs have used a second propeller and sometimes a second source of power for forward propulsion. This, again, is so serious a handicap that it spells the difference between success and failure.

The solution proposed, and the only one which appears to show a high efficiency, is that of using the lifting rotor system itself as the means of forward propulsion. This can be accomplished by tilting the axis of rotation in order that the thrust vector may slope forward and produce the required horizontal component.

Any thought that the forward slope will necessarily be so great as to seriously impair the vertical component of force required for lift, is immediately allayed by a consideration of the comparatively small angles of glide of which a modern efficient fixed wing airplane is capable. In a glide, the forward motion of the airplane is maintained solely by reason of the forward slope of the lift vector of its wings. In the present calculations, an angularity of the axis of rotation, amounting

* Presented at a meeting held Thursday, April 2, 1936.

to about 8 or 9 degrees of forward slope, is all that is necessary to achieve a top speed in the neighborhood of 150 miles per hour.

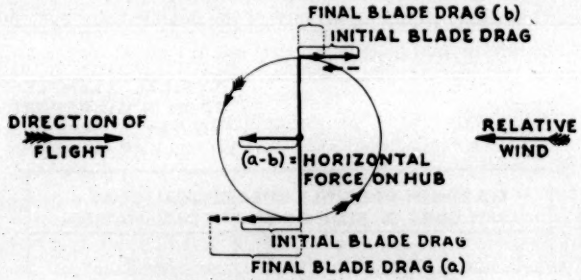
It has been pointed out that, for reasons of stability and the elimination of gyroscopic precession, an articulated rotor system of the Cierva type is essential. Perhaps the most remarkable characteristic of the articulated rotor system and, in fact, of a feathering system, in which the blade angles change in the course of the cycle by feathering rather than by flapping, is the lower resistance to forward motion of these rotor systems at small angles of yaw, when compared with the rigid type. It is believed that this phenomenon has not been fully understood in the past, and many investigators of propellers and rotors operating at angles of yaw have failed to appreciate the importance of blade flexibility upon the aerodynamic characteristics.

In the diagram (Fig. 7), the forces on both rigid and articulated rotor systems, moving through the air sideways (in yaw), are compared. It will be realized that the blade which is momentarily approaching *into* the relative wind will have a higher resistance than that which is on the opposite side of the cycle and momentarily traveling *with* the relative wind. In the upper diagram, pertaining to the rigid system, the initial blade drag, assuming no forward motion in yaw, is shown to be equal on both sides of the cycle. When forward motion in yaw takes place, an additional increment of drag is *added* to that blade which is momentarily at the phase angle *approaching* the relative wind and *subtracted* from that blade which is momentarily traveling *with* the relative wind. Thus, we have a final blade drag on each side of the cycle, represented by the vectors marked (a) and (b). Since these drag forces are unequal, there is an unbalanced moment about the hub or center of rotation, which will result in a horizontal force on the hub equal to $(a - b)$. The magnitude of this force is clearly indicated in the diagram.

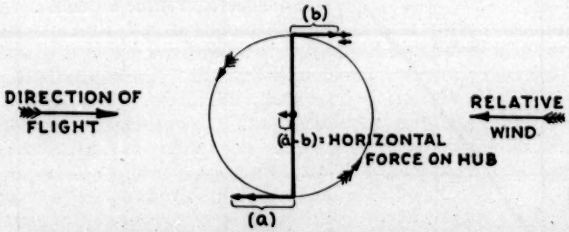
If we turn to the lower diagram relating to the articulated or feathering system, we find conditions different, due to the fact that the *induced* drags of blades located at phase angles on opposite sides of the cycle in relation to the relative wind are equal. This is because the induced drag is a direct func-

tion of the lift, and in the articulated and feathering systems the blades flap or feather to equalize their respective lifts and eliminate the asymmetry in lift of the rigid rotor. Therefore,

FIG. 7.



RIGID ROTOR SYSTEM



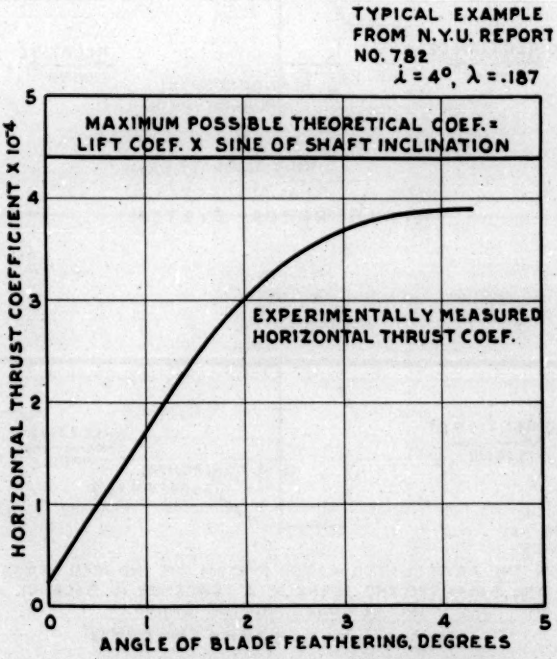
IN THE ARTICULATED ROTOR SYSTEM THE INDUCED DRAGS ARE BALANCED AND THERE IS A TENDENCY TO BALANCE THE RESIDUAL PROFILE DRAGS

ARTICULATED ROTOR SYSTEM

the only difference in drag on opposite sides of the cycle is the difference in the residual profile drags. The unbalanced moment, therefore, is extremely small, especially since blade sections of low profile drag are employed. Thus, the hori-

zontal force on the hub ($a - b$) is very small, as indicated in the lower diagram. It will be observed that this horizontal force at the hub is, in both rigid and flexible rotor systems, in the direction of the relative wind and, therefore, opposes the yaw or, in the case of a rotating wing aircraft, the desired forward motion. The importance of the flexible rotor system is very apparent.

FIG. 8.



Effect of blade feathering in permitting development of thrust by rotor shaft inclination.

In order to investigate experimentally the nature of this reduction in horizontal drag force on the hub, wind tunnel tests were made using a four-bladed feathering system. The

results, it will be understood, are comparable with those which would have been obtained from a flapping system. They are shown in Fig. 8. Throughout the tests, the axis of rotation was tilted forward by an angle of four degrees, and in still air the horizontal thrust coefficient was measured for a given constant rotor speed. Obviously, the theoretical maximum horizontal thrust coefficient will be the lift coefficient of the rotor multiplied by the trigonometrical sine of the shaft inclination; in this case four degrees, and this will be uniform in both the rigid and flexible rotors.

In the tests, the wind speed, the rotor speed and the four-degree tilt of the rotor axis were maintained constant. The first readings of horizontal force were taken with the blades rigid. In this condition, the horizontal thrust coefficient was extremely small, clearly because of the large horizontal drag force at the hub due to the unbalanced blade drag moment. As the feathering was allowed to increase, a maximum horizontal thrust coefficient of nearly .004 was obtained. At this point, the curve leveled off, as will be seen from the plotted results in Fig. 8. The difference between the theoretical maximum coefficient, which is shown in the chart by the horizontal line, and the maximum experimentally-measured coefficient is equal to the small residual horizontal drag force on the hub due to the unbalanced profile drags, the induced drags at this point being equal. While this effect is in no way an aerodynamic drag, it has precisely the same effect. This will be rather strikingly displayed if the chart of Fig. 8 is viewed upside down. Then it will be seen that the curve is similar to a characteristic drag curve, with minimum drag or resistance appearing to come at four degrees of feathering and increasing as the feathering angle is reduced.

Level Flight.

Let us now set down the elementary mathematical relationships which enter into the conditions of level flight of translation of the rotating wing machine, using the tilted rotor axis as a means of forward propulsion. Assuming that no stall angles occur during the rotating cycle of the system (and later we shall see that this is a fair assumption), and that the rolling moment may be balanced, the level flight power require-

ment, P', may be treated as the sum of the three terms: induced power P_i'; profile power P_p'; and parasite power P_s. Thus,

$$P' = P_i' + P_p' + P_s.$$

From momentum theory the vertical induced air velocity is:

$$u = \sqrt{\frac{W}{2\rho A'}},$$

A' being the area passed over by the blades in unit time.

The horizontal induced component is found to be negligible.

Now,

$$A' = A + 2RV$$

and

$$P_i' = Wu = W\sqrt{\frac{W}{2\rho(A + 2RV)}}.$$

The element of profile power, U being the circumferential velocity component and neglecting radial components, is:

$$dP_p' = \tfrac{1}{2}\rho C_{D_0} c U^3 dr$$

and, since $U = \Omega(r + \lambda R \sin \psi)$,

$$dP_p' = \tfrac{1}{2}\rho C_{D_0} c \Omega^3 (r + \lambda R \sin \psi)^3 dr,$$

ψ being the instantaneous angular blade displacement from the downwind position, and λ, the tip speed ratio $V/\Omega R$. Expanding and integrating over the whole blade and then over the revolution,

$$P_p' = \tfrac{1}{8}\rho C_{D_0} \sigma A \Omega^3 R^3 (1 + 3\lambda^2).$$

Simplify,

$$P_p' = P_p(1 + 3\lambda^2).$$

If D is the structure drag at unit velocity,

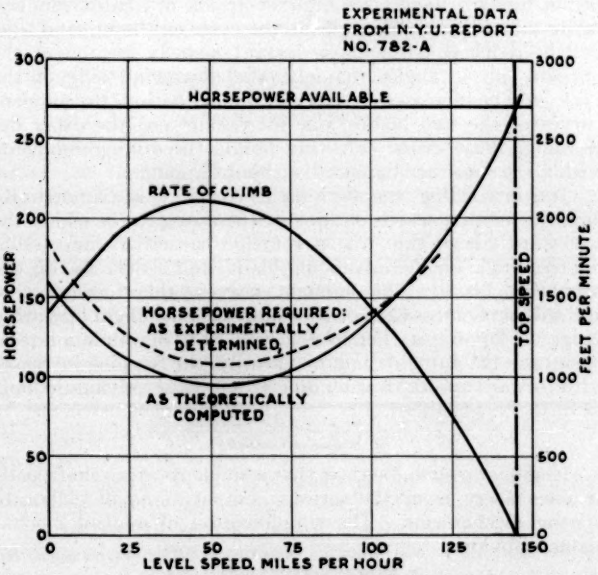
$$P_s = DV^3.$$

Therefore, level flight power required is:

$$P' = W\sqrt{\frac{W}{2\rho(A + 2RV)}} + P_p(1 + 3\lambda^2) + DV^3.$$

This expression will be modified to the extent by which the drag of the rotor is subject to the small horizontal force arising from the unbalanced couple, resulting from inequality in relative profile drags on oppositely-disposed blades, as already pointed out.

FIG. 9.



Flight performance of typical 300 horse-power helicopter.

In Fig. 9, performance curves for a typical 300 horsepower helicopter, calculated by means of the mathematical relationships already set forth, are shown, together with the experimentally-determined horsepower curve as developed from recent wind tunnel tests. In this connection, no attempt has been made to assume a low structural drag, as will be possible in the ultimate machine of the proposed type.

It has been erroneously believed that a rolling moment

balance, that is, a balance of the forces tending to roll the ship sideways in flight, such as is attained in the articulated rotor of the autogiro, is impossible of achievement with the helicopter, in which the axis of rotation is tilted forward. This, however, will not prove to be the case. It will be understood that, as the axis of rotation is tilted forward to attain forward flight, the angle of attack of blades, momentarily located at phase angles in the cycle on the upwind side, will be reduced, while those instantaneously located at the opposite phase angles, namely, the downwind side of the cycle, will be increased. At a certain inclination, the moment curves of the two blades, one increasing and the other decreasing, must cross. At this point, the rolling moments within the rotor are balanced without flapping.

It is interesting to note that this condition is diametrically opposite to that which obtains in the autogiro, in which the backward tilt of the axis of rotation causes an increase in relative angle on the advancing blade, and a decrease on the retreating blade. The moment curves, therefore, diverge and will never cross each other within the level flight operating range. Flapping is, therefore, necessary to maintain a lateral balance in the autogiro and, necessarily, the flapping increases with forward speed, thus tending to set an aerodynamic limit on autogiro top speed.

(d) Mechanical Complexity.

It will, of course, be clear that a single rotating shaft leads at once away from the serious complications of elaborate driving mechanisms. The simplification of control mechanisms is obvious.

(e) Excessive Weight and Parasite Drag.

The structural and mechanical complexities of the helicopter, to which reference has already been had, have constantly resulted in structural weights and parasite resistances far exceeding these factors in the conventional fixed-wing airplane. The light articulated rotor system of the autogiro, combined with the closely-coupled power drive which would be adopted in a power-driven machine, go far toward reëstablishing equality in weight with the airplane. The elimination of the propeller in the helicopter tends further

to reduce structural weight, and the commensurate elimination of aerodynamic propeller losses serves to balance the additional parasite drag of the anti-torque surfaces.

(f) Gyroscopic Precession in the Rotor System.

As has already been pointed out, gyroscopic precession is not present in the articulated rotor system. This problem, which has been a major one in helicopter development in the past, is thus no longer present in the hypothetical type of machine now being considered.

(g) Instability and Ineffective Control.

Stability in vertical operation, as in forward speed, is inherent in the action of the articulated rotor in furnishing a restoring moment by reason of a change in the angle of the thrust vector to match each external disturbance. It is well known that the stability of any type of rigid lifting rotor has proved to be greatly deficient.

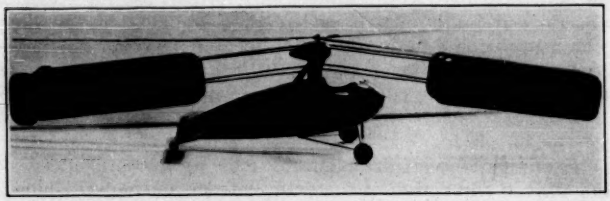
Longitudinal and lateral control of an aircraft having an articulated rotating wing system, with the angularity of the rotor axis controllable from the pilot's seat, has been fully demonstrated in the "direct control" type of autogiro, and has been clearly exhibited in the motion pictures.

In the mathematical derivation of level flight performance, the assumptions were made that the rolling moments balance, and that no stall angles occur during the rotor cycle. A detailed analysis of the dynamics of the rotor system has been necessary to justify these assumptions.

As in the autogiro, so also in the helicopter, a constant rotor speed is highly desirable for efficiency and smoothness of operation. A pitch regulator capable always of setting the pitch of the blades to a value such that the rotor will absorb the power input without change of rotational speed, regardless of the throttle setting, is necessary. Furthermore, the mechanism must provide for the fact that the blade pitch required for maximum performance in level forward flight is considerably less than that necessary for vertical flight, and that the critical condition in regard to blade stall is in hovering flight.

CONCLUSIONS.

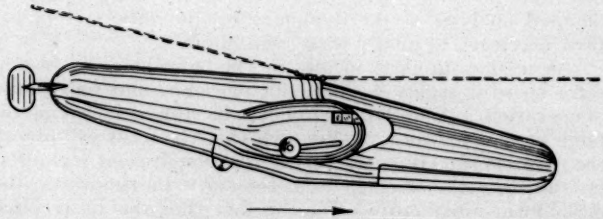
Reviewing the statements and analyses which have been made in this paper, I have no hesitation in predicting the ultimate development of the helicopter as a successful type of rotating wing flying machine.



On the desk in front of me is a model of the Platt helicopter, an aircraft which incorporates the features and characteristics which I have outlined. Only a little imagination is needed to foresee the possible helicopter of the future as depicted in Fig. 10.

The history of transportation is inevitably repeating itself. As we look back to the early days, we recall that travel was originally considered largely an individual problem. For distances too far to walk, a man rode horseback.

FIG. 10.



Prospective high-speed cabin type helicopter.

The importance of travel between communities rapidly unfolded the need for mass transportation, and the stagecoach appeared. Travel in those days was comparatively easy and

eminently safe, and the means of locomotion was largely under perfect control. I use the term "control" in a somewhat broader sense than is customary today. I mean, when I say "control," not only the ability to control the operation of the transportation vehicle, but I refer also to the wide range of adaptability of the vehicle. Thus, it is entirely within the control of the horseback rider to move practically wherever he pleases.

The arrival of mechanized transportation on a large scale came with the steam engine, but the limitations of this means of transportation were early made apparent. The steam engine was cumbersome; it required a solid fuel and a large volume of water had to be carried. The weight of the power unit made it necessary to construct a special form of track, the permanent way of our railroads today. It overcomes the very apparent lack of adaptability and control of the steam train, which needs its permanent way in order that its serviceability and safety may be a maximum. If the railroad train should leave the tracks it is wrecked.

The railroad train takes the right of way wherever it goes; all other forms of ground transportation stand back for the train to pass. It cannot be stopped in a hurry; it cannot be started in a hurry. It must have large depots and stations at which to begin and end its journeys. The inherent lack of control of the railroad train is further overcome by an elaborate signal system, by automatic brakes, etc. etc.

Not until the introduction of the gasoline motor did we find it possible to develop a satisfactory individual means of mechanical transportation—convenient enough, controllable enough and safe enough to be operated at the hands of the average man. The gasoline motor is inherently light; it uses a convenient liquid fuel; it is highly flexible; and, when built into an automobile, it contributes to the creation of a vehicle, large or small, which is very controllable, highly adaptable, which may be started and stopped at will, and may be taken almost anywhere. Roads are a convenience rather than a necessity; no permanent way is required, nor is the right of way a prime requisite in the operation of the automobile. Thus, very largely on account of these inherently favorable characteristics, the automobile has brought transportation,

safe and convenient, within the practical reach of the average man.

Now, let us look for a few minutes at the far more recent history of travel by air. From its earliest conception, aviation was a means of individual transportation; Wilbur Wright, with his brother Orville as a spectator, on December 17, 1903, flew alone, for the first time in history, in the first successful, power-driven airplane. Except for the war period, when the airplane became a weapon rather than a means of transportation, aviation has developed with high speed, point to point travel as its primary function. However, it has rapidly become apparent that the airplane is, in the sense in which I have defined the term, largely an uncontrollable vehicle within itself. It cannot really and in safety go always precisely where its operator pleases. It cannot be momentarily started and stopped at will; considerable space and time are needed for this.

Only since these facts have been realized has air travel been made the safe and reliable means of transportation which it is today. The safety and reliability of our air lines are, in no small degree, the result of the permanent ways which we have constructed across the country. An air route is as tangible and material a thing as is a railroad track. It consists of a string of landing fields with airports dotted here and there and at its extremities. It consists of a series of light beacons, radio beacons and two-way radio transmission stations—the block signals of the air. A large airliner needs large stations in which to stop and take on or deposit passengers, mail or freight. If, in the course of its flight, the airliner leaves its permanent way—its airway—it is, like the railroad train, liable to wreck, except in so far as it has the advantage over the latter, in that it is capable of returning to the "tracks."

I emphasize that air transportation today is safe and reliable largely as a direct result, not only of the tremendous progress which has been made in the art of aircraft design and construction, including that of the engines, but also by reason of the highly complex permanent way system which has been developed, and which we call airways.

I offer for your consideration the thought that the develop-

ment of the rotating wing machine, the autogiro and the helicopter, heralds the arrival of the safe, adaptable and highly available individual "automobile" of the air. This type of machine may be started and stopped at will in any place large enough to contain its dimensions. It needs no right of way; it needs no permanent way; it can be taken practically anywhere that its operator chooses. It can be flown fast or slowly; it can be stopped in the air. At present, I see it in no sense as a direct rival of the airplane any more than the automobile is, in itself, a rival of the railroad train, although the future relationship between the two in the air may possibly repeat the relationship which now exists between the two on the ground.

The autogiro and the helicopter have been criticized by engineers as too complicated. Not only aeronautical engineers, but prominent engineers in other fields, point to the modern airliner, with its clean appearance and simplicity of outside form, as "looking right." There is little to go wrong, they say, in a vehicle of this appearance. On the other hand, they point to the autogiro, and they will probably point to the new vertical lift rotating wing machines, which have been discussed, as too complicated. These types have been described as "gim-cracks." Perhaps, they are correct in their comparisons, but I do not think so.

I recall the early history of the automobile, when the only way to start the motor was with the aid of the strong right arm of the driver. One day, somebody proposed a self-starter; a battery, a generator, an electric motor, a wiring system, gears, a switch—a complicated mechanical system, indeed. "It will never work," said the engineers and operators; "it is too complicated; no car can ever be expected to carry around such a mechanism." Yet, today, no automobile is considered complete unless it carries an electrical installation as complicated, in a measure, as the system of the Philadelphia Electric Company; an electrical system capable of starting and running the car, of running the lights, of operating the horn, the radio, the heater, the stop lights, the windshield wiper, the defrosters and, in the not far distant future, the air-conditioning system. The automobile today is a far more intricate and complicated mechanism than the

steam locomotive. It is, essentially, a delicate mechanism, yet its design and construction have been developed to the point where it seldom fails in any respect. Out of twenty-four million automobiles in the United States, and possibly fifty million operators, I question whether more than one in a thousand of these operators has the faintest idea of just how and why his automobile works, but it does work; it practically always works; it is easy to operate and, in itself, it is extremely safe.

The rotating wing aircraft of the near future will work, will always work, will be easy to operate and, in itself, will be extremely safe.

ON THE ORIGIN OF THE CONTINENTS AND THEIR MOTIONS.

BY

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ABSTRACT.

An approximate quantitative study has been made of the relation of the observed asymmetry of the earth to certain aspects of geological evolution and to the problem of the origin of the solar system.

Geophysical data from several sources emphasize the unusual nature of the Pacific basin with its encircling mountain chains and suggest that the sub-Pacific layers of appreciable strength are slightly denser (1 or 2 per cent.) than elsewhere. It is shown, as a result of this asymmetry and the isostatic adjustment of the continents, that the mass per unit area of the earth's outer shell in Pacific regions is about 3/100 per cent. greater than in the continents. This relatively slight mass asymmetry is found to produce geologically important tangential forces on the continents of gravitational origin which frequently compress their boundaries playing an important part in mountain building and may actually produce continental motions. The force on North America urging it to the south and west, for example approximates 10^{25} dynes and is adequate, or at least nearly adequate, to crush or produce over thrusting in the resisting Pacific basin, permitting continental motion with a velocity of the order of an inch per year. The author's earlier theory of the earth's origin, which was based upon purely astronomical facts (*Phys. Rev.*, 39, 130, 311 (1932)), is found to be particularly adapted to describe the origin of the continents and the observed asymmetry of their distribution.

The observational foundations underlying the more basic facts of geology have been supplemented in recent years by seismic and other very important geophysical data. These data bear out well the inferences of geologists in regard to the structure of the earth's surface and may be used to provide a moderately satisfactory basis for further quantitative investigation. Wegener and his school of geologists have followed the suggestion of F. B. Taylor (1) and believe that a great parent continent existed during the early history of the earth which broke up and formed the present ones (2). Wegener has worked out these ideas in far more detail than

any physical investigation could be, but the present analysis of continental formation is consistent with some of the more general conclusions which he has drawn and places certain general aspects of the hypothesis on a quantitative basis. The conclusion may be stated in advance that, subject to certain reasonable assumptions based on the work of earlier investigators, systems of gravitational forces are set up in the shell of the earth, as a result of its non-uniform cooling, which are of the right order of magnitude to produce motions of the continents, even against a resisting crust of moderate strength and may have transported them great distances in the course of geological time. The form of the expressions which give the magnitude of the forces suggests that such motions became important only after the earth's development was well advanced and that the velocity of transport is perhaps of the order of an inch per year. The analysis further suggests that the strength of the Pacific shell may be barely sufficient to resist motion and the continents may or may not be in stable equilibrium at the present time.

ASYMMETRY OF THE EARTH.

A great circle whose northerly pole coincides with the intersection of the Tropic of Cancer and the prime meridian defines a plane through the center of the earth which roughly divides it into continental and oceanic hemispheres. Further, a majority of the great mountain ranges of the world are within a 1,000 kilometers of this dividing plane and there is evidence that these marked surface asymmetries are indicative of more deep seated differences. For example, it has been known for more than a century that the earth's magnetic field is not uniformly distributed about its axis of spin, but behaves as if the center of magnetic activity were displaced from the axis toward the Pacific basin by some hundreds of kilometers (16).

The inferences drawn from the consideration of magnetic data and the known surface features are well supported by seismic and radioactive data. As a result of his analysis of seismic investigations, Gutenberg has concluded that continental rocks were absent under the Pacific and "that the region comprised within the physical limits of the Pacific

Ocean has one kind of structure and all other regions of the earth have another" (3). He notes further that the non-Pacific areas are covered with continental material varying from a layer 20 kilometers thick under the Atlantic to 40 or 50 kilometers under the continents. There is considerable additional evidence indicating that the outer sub-Pacific layers are somewhat denser than those underlying the continents and that this excessive density extends well into the earth. For example, it is well known that continental or acidic rocks release several times as much radioactive heat as do the basic rocks and therefore the presence of a thick continental layer will act like a heated blanket and reduce the rate of cooling of the deeper layers in an important manner. Although the thermal conductivity of the acid rocks is 50 per cent. greater than the basic ones and therefore the initial cooling of the outermost continental material would be more rapid than oceanic, yet over a long period of time the deep layers of the latter would cool the most rapidly because of the low radium content of the overlying layers. A calculation of the extent of cooling under the Pacific following the analogous investigation of the cooling of continental regions by L. H. Adams shows that the Pacific layers down to several hundred kilometers must be two to four hundreds of degrees cooler than the continental regions (4). A more detailed calculation of the overall cooling has been carried out by Jeffreys (5) and he concludes that the blanketing effect of the outer continental radioactive layers is large and as a result of cooling alone, the density of the sub-Pacific layers is perhaps $2\frac{1}{2}$ per cent. greater than the subcontinental ones. It will be convenient here to accept Jeffreys' estimate of the cooling without detailed reëxamination.

In the light of evidence from the several different sources mentioned above, it seems necessary to conclude that the earth is unsymmetrical and that this dissymmetry is not merely superficial but is quite general in nature. The foregoing paragraphs have considered the important physical factors which can give reliable information regarding conditions well below the earth's surface, with the exception of gravitational forces. It will be shown in the following paragraphs that gravitational forces also indicate the presence of a marked asymmetry within the earth.

It is a well known property of the hydrostatic state that the forces acting on a floating body are always normal to the free surface and therefore may not give the floating body a tangential acceleration. It is convenient therefore to divide the earth into an outer shell which is assumed to be composed of material having appreciable strength in shear and a quasi liquid inner shell and core which supports the outer shell. Because of the assumed liquid like nature of the inner shell and core material, it is incapable of contributing to tangential accelerations in the surface layers and in the determination of mass asymmetries it is necessary to examine only the system of forces that may be set up in the outer layers of the earth by variations of density within it. If the mass distribution in the outer shell having appreciable strength is uniform, then it follows from symmetry that no tangential force may be produced. Now, the usual inference drawn from the observational data concerning isostasy and the statement commonly made in the literature is that the mass per unit area of the outer shell when averaged over a reasonable area is constant over the entire earth (6). On the basis of such a statement one would logically conclude that the facts of isostasy deny the possibility of systematic tangential gravitational forces over large sections of the earth's outer shell. However, the usual statement is not sufficiently precise for the present investigation and must be restated.

In order that the facts of isostasy may be described it is necessary to suppose that mass is transported by plastic flow from one place to another in regions below the outer shell where the earth material behaves much as if it were a highly viscous liquid. Now the elementary principles of hydrodynamics show that such motions along a gravitational equipotential surface arise from pressure gradients and therefore over any gravitational equipotential surface located in regions of inappreciable strength, the pressure must be a constant if the quasi liquid material is to be in static equilibrium. This statement is equivalent to the usual one which notes that in the hydrostatic state surfaces of equal gravitational potential, pressure and density all coincide. The pressure at any selected level is given by the product of the mass per unit area and mean gravity above the level so one

concludes that large sections of the continents or oceans are in equilibrium only if the product of mass and mean gravity within typical columns having equal area and extending downward to some reference gravitational equipotential surface located in quasi liquid regions, is a constant. This precise statement of the principle of continental equilibrium permits small but geologically important systematic deviations from uniformity of mass over the earth's outer shell (7).

CALCULATION OF THE FORCES.

The system of gravitational forces set up in a shell having any arbitrary distribution of mass may be worked out employing the methods of harmonic analysis or in certain special cases can be worked out by direct integration. This method of analysis is laborious, comes out in a complicated form, and tends to conceal the simple physics of the problem. Therefore, the following approximate methods have been adopted and are satisfactory, at least, when used with present incomplete data.

If M is the mass per unit area of the earth's outer shell of appreciable strength lying above some suitable equipotential surface and g is mean gravity within the shell, then for any region of the shell to be in equilibrium, it is necessary that

$$Mg = \text{Const.} \tag{1}$$

Differentiating this logarithmically with respect to some arbitrary coördinate angle θ as measured at the center of the earth, we have

$$\frac{1}{M}\frac{dM}{d\theta} = -\frac{1}{g}\frac{dg}{d\theta}. \tag{2}$$

Equation (1) correctly implies that due to the rotation of the earth and the appreciably lower effective gravity of equatorial regions, the mass per unit area of the outer shell there will be greater than elsewhere. Thus, the earth is a spheroid rather than a sphere. However, it is clear that this spheroidal form introduces no uncompensated tangential forces in the outer shell since the distorted figure of the earth existed when the surface material was in the liquid state and could not support a shearing force. Therefore, except for the important possi-

bility of effects arising from changes in the earth's angular velocity which will be considered in more detail elsewhere, one may properly discuss the system of forces arising from the cooling of the shell by considering the much simpler case of a non-rotating earth.

Consider a non-rotating earth in which the outer shell is of constant density and the density of the quasi liquid core increases toward the center. Assume that the gravitational acceleration is g_0 at sea level. It will be shown in Equation (9) that mean gravity g in the outer shell of arbitrary mass per unit area M is

$$g = g_0 - 2\pi\gamma M + \frac{2\pi\gamma M^2}{3\rho R}, \tag{3}$$

where R is the outer radius of the shell; γ the gravitational constant, and ρ the density of the shell. In case several concentric shells are necessary to represent observation, further terms may be readily added and the average taken. Since g varies with the density of the shell according to Equation (3) and since the average density of the sub-Pacific shell according to Jeffreys' calculation is some 2 per cent. greater than the average in the subcontinental zone, then from Equation (1) it follows that the mass per unit area over the Pacific is roughly 3/100 per cent. greater than elsewhere. This small mass asymmetry in the outer shell sets up systematic tangential gravitational accelerations of considerable magnitude which urge the bordering continents toward the Pacific basin.

If now the density of the earth's outer shell is allowed to vary slowly over a limited range with the arbitrary coördinate angle θ, then differentiating Equation (3) we have approximately

$$\frac{dg}{d\theta} = -2\pi\gamma\frac{dM}{d\theta} + \frac{4\pi M}{3R\rho}\frac{dM}{d\theta} - \frac{2\pi M^2}{3R\rho^2}\frac{d\rho}{d\theta}, \tag{4}$$

whence multiplying by M, dividing by $g_0 = 4\pi\gamma\rho_0 R/3$ and noting Equation (2), it is found that

$$-\frac{dM}{d\theta} = \frac{M}{g}\frac{dg}{d\theta} = -\frac{3M}{2\rho_0 R}\frac{dM}{d\theta} + \frac{M^2}{3R^2\rho\rho_0}\frac{dM}{d\theta} - \frac{M^3}{2\rho_0 R^2\rho^2}\frac{d\rho}{d\theta}, \tag{5}$$

where ρ_0 is the mean density of the earth and R its radius. Therefore

$$\frac{dM}{d\theta} = \frac{M^3}{2\rho_0 R^2\left(1 - \frac{3M}{2\rho_0 R} + \frac{M}{3R^2\rho\rho_0}\right)} \frac{1}{\rho^2}\frac{d\rho}{d\theta}. \tag{6}$$

Consider next a calculation of the gravitational potentials of an unsymmetrical earth shell. Assume first that the shell is spherical, having an outer radius of R and an inner one of $R - T$, and that its density is uniform. The potential of such a shell is found to be (7)

$$\varphi_R = -4\pi\gamma TR\rho\left(1 - \frac{T}{R} + \frac{T^2}{3R^2}\right) \tag{7}$$

on the outside surface and

$$\varphi_{R-T} = -4\pi\gamma TR\rho\left(1 - \frac{T}{2R}\right) \tag{8}$$

on the inside surface. The average radial gravitation acceleration within the shell is evidently $(\varphi_R - \varphi_{R-T})/T$ and since $\rho T = M$ it follows that

$$g = g_0 - 2\pi\gamma M\left(1 - \frac{M}{3R\rho}\right). \tag{9}$$

Now if the mass per unit area of the shell is non-uniform, an average tangential acceleration a_t will be produced and this may be calculated from the average value of Equation (7) and Equation (8) by forming the negative space gradient. Whence

$$a_t = -\frac{1}{R\left(1 - \frac{T}{2R}\right)}\frac{\partial\varphi}{\partial\theta} = 4\pi\gamma\frac{dM}{d\theta}\left[1 - \frac{T}{4R} + \cdots\right] \tag{10}$$

or

$$\frac{a_t}{g_0} = \frac{3}{\rho_0 R}\frac{dM}{d\theta}\left[1 - \frac{M}{4\rho R} + \cdots\right], \tag{11}$$

which becomes, by aid of Equation (6)

$$\frac{a_t}{g_0} = \frac{3M^3\left(1 - \frac{M}{4\rho R} + \cdots\right)}{2\rho_0^2 R^3\left(1 - \frac{3M}{2\rho_0 R} + \frac{M^2}{3R^2\rho\rho_0}\right)}\frac{1}{\rho^2}\frac{d\rho}{d\theta} \doteq \frac{3T^3\rho}{2\rho_0^2 R^3}\frac{d\rho}{d\theta}, \tag{12}$$

where ρT has been substituted for its equivalent M. The magnitude of this ratio for the North America-Pacific region approximates 7×10^{-5} if subsequent values of the quantities are adopted. Or in popular terms, the "equivalent downgrade" tending to move all masses toward the Pacific basin is about 1 : 15,000.

In general, one is not particularly interested in the tangential acceleration a_t but rather the tangential stress. Consider a horizontal prism of unit area lying in a continent and partaking of the direction of the tangential acceleration. The stress Q on the end of the prism, if it is in equilibrium, is

$$Q = \int a_t \rho ds, \tag{13}$$

where ds is the element of length. By use of Equation (10) Q may be evaluated. Performing the integration and noting that $ds = Rd\theta$ and that the density variation is always moderately small it is found

$$Q = 2\pi\gamma \frac{T^3\rho^2}{R\rho_0}(\rho_2 - \rho_1). \tag{14}$$

Therefore, except for the limitations imposed by assuming that the density did not vary too rapidly from place to place in the shell and small correction terms which arise from the curvature of the continent and finite thickness of the layer, it is seen that the tangential stress depends on the difference in average density at any two selected points and the cube of the thickness of the earth's outer shell of appreciable strength. Since the boundaries of the continents are likely to coincide with regions of changing density they are usually under a geologically appreciable compressional stress and it is considered that this may be responsible in many cases for the presence of mountain ranges paralleling the continental coast lines. Moreover, since the density differences probably depend primarily on differential cooling and hence on the extent of the regions, it seems probable that the circum-Pacific mountain chains were produced in part at least by the foregoing system of forces. The matter will be considered in another paper.

The result expressed by Equation (14) must be interpreted with some care and may be applied only to regions of extent

comparable to or greater than the thickness of the shell. The difference in density of the shell below a typical continent and the density below the Pacific is probably greater than that between the former and the Atlantic shell. This conclusion is based on the observations of Gutenberg (3) and others and upon Jeffreys' (5) estimates of suboceanic and subcontinental cooling. The former points out that although the Pacific basin has no "continental layer," the Atlantic has such a layer about 20 km. thick while the thickness of the layer approximates 50 km. under the continents. As a first approximation, one may therefore assume that the difference in density between the continental shell and the Atlantic shell is something like one-half that between the former and the Pacific. On certain assumptions which appear allowable, Jeffreys (5) has calculated the increase in density which has resulted from the cooling of the outer shell. He estimates that in the outer 400 km. of the Pacific shell the density has increased $7\frac{1}{2}$ per cent. during geological time, while under the continents it has increased only 5 per cent. Therefore, the difference in density between oceanic and continental layers is $0.025 \cdot 3 = 0.075$ gm./cm.^{3} averaged down to a level of 400 kms. and for the entire outer shell down to the level of inappreciable strength or 1200 km. it is perhaps two-thirds of the above estimate. We adopt therefore as the most probable values

$$\rho(\text{Pacific}) - \rho(\text{N. America}) = 0.050 \text{ gm./cm.}^3$$

and

$$\rho(\text{Atlantic}) - \rho(\text{N. America}) = 0.025 \text{ gm./cm.}^3.$$

Adopting further, Gutenberg's estimate (3) of the thickness of the earth's outer shell of appreciable strength or $T = 1{,}200$ km., taking $\rho = 3$ gms./cm.^{3}, $\rho_0 = 5.5$ gms./cm.^{3} and γ the constant of gravitation as 6.67×10^{-8}, it is found from Equation (14) that Q(Pacific-N. America) $= 0.95 \times 10^8$ dynes/cm.^{2} whence the total force acting to the southwestward on the boundary is QWT, where W is the dimension of the continent at right angles to the force or approximately 5,000 km., and thus the total force amounts to about 5×10^{24} dynes. In comparison with this the stress on the Atlantic margin using the foregoing data is evidently Q(Atlantic-N. America)

$= 0.47 \times 10^8$ dynes/cm.^{2} and the total force acting in a southeastward direction is something like 2.5×10^{24} dynes. Therefore the net force acting on the continent if it were free to move would depend on the difference in mean density of the Atlantic and Pacific shells and would be roughly the vector sum of the above forces or approximately 2.5×10^{24} dynes which will act in a generally southwestward direction.

The foregoing tangential gravitational force acting on the North American continent is opposed and balanced by two other great forces; the first is the resisting strength of the cool and supposedly strong sub-Pacific shell and the second is the viscous force acting in the weaker regions of the continental shell if it is in motion. The average resisting strength S_b of the Pacific basin shell probably does not greatly exceed 10^9 dynes/cm.^{2}, which is roughly the crushing strength of basalt. Therefore, since the Pacific margin is roughly 5,000 km. long (W) and the thickness of the shell of appreciable strength is T, the maximum possible resisting force F of the margin is $F = S_b \cdot W \cdot T$ or about 6.10^{25} dynes. This estimate is probably too high because the material below 100 km., say, may fail to support a stress of 10^9 dynes/cm.^{2} and the resisting force may only approximate 5×10^{24} dynes. Now, if one irregular body is resisted in its motion by another, certain projections and irregularities are subjected to stresses many times the average stress, and failure may occur locally. Moreover, the outermost layers of the earth, probably take a large share of the impressed force because of its great strength, while the deeper layer may yield plastically. It, therefore, seems possible that a total impressed force somewhat less than the average resisting force of the Pacific margin may actually succeed in producing over thrusting or in crushing it and thus permit small, but geologically appreciable, continental motions.

Next consider the velocity with which the continents might move *if they were free* and encountered no marginal resistance. The velocity of motion V of a given surface over a viscous liquid is given by the well-known relation defining the coefficient of viscosity

$$V = \frac{F}{A}\frac{t}{\eta} = \frac{Q_N TR}{2L\eta}, \qquad (15)$$

where F/A is the tangential force per unit area, t is the thickness of the liquid layer—taken here somewhat arbitrarily as $R/2$, L is the continental dimension in the direction of the tangential acceleration and Q_N is the resultant stress which is effective in producing motion. For the purpose of illustration suppose that the area of North America is taken to be 25×10^{16} cm.^{2}, $t = R/2 = 3.2 \times 10^8$ cm. and that the coefficient of viscosity η is Haskell's value (9) 3×10^{21}, while the net force acting on the continent is that just calculated or 2.5×10^{24} dynes, then employing Equation (15) it is found that $V = 30$ cm. per year. This may be excessive but if the calculations were made for the conditions existing in the geological past when the thickness of the outer shell was 500 km., it is found that the free velocity is about 0.8 cm. per year. The exact values calculated have no particular significance because of the uncertainty of the data and are given simply to show that the magnitude of the forces are about right to produce a separation of the continents to their present positions in a time of the order of a few hundred million years.

In any actual circumstance it is certain that the continents are not perfectly free to move but must be resisted by the strength of the shell material at the forward boundary of the oncoming continent and hence will move slower than the "free" velocity just calculated. However, the above estimates show that the resisting force necessary to maintain the North American continent in complete equilibrium must approximate 5×10^{24} dynes whereas the maximum possible force available approximates 6×10^{25} and actually is probably considerably less than this value because of the weakness of the underlying layers. Therefore, it appears that the present resistance of the Pacific basin may be sufficient to maintain the North American continent in equilibrium but it is by no means certain. The present investigation may only say that the equilibrium is uncertain and that the forces acting are of roughly the right magnitude to produce instability with resulting slow continental motion of the order of an inch per year. A more complete and detailed knowledge of the observational facts will be necessary before definite conclusions may be drawn, but the foregoing suggests that the

broader aspects of the Taylor-Wegener hypothesis of continental motion may be consistent with other geophysical data.

ORIGIN OF THE CONTINENTS.

The foregoing sections have emphasized the marked asymmetry of the earth, the continental and oceanic hemispheres, the systematic differences in suboceanic densities, the marked distortion of the magnetic field and finally systematic differences in the distribution of mass in the earth's outer shell. Of what significance are these facts in relation to the important problem of the origin of the solar system?

There appears to be no escape from the conclusion that at least some of the observed large scale terrestrial asymmetries were primitive and that the mode of formation of the earth must therefore have been such as to produce them.

Several theories of the origin of the solar system have been proposed but of all the roughly quantitative theories known to the author, only one suggests, in the transition from the parent star to a planet, that the earth preserved a liquid-like structure. The other theories on the contrary assume that the planets were condensed from great clouds of gas extracted from the sun by an exceedingly improbable accident, were condensed from nebulous material or were formed by the aggregation of unnumbered planetesimals. It is quite impossible to understand in terms of classical dynamics the mechanism of condensation of such a hot gaseous mass on an initially small nucleus and even more difficult to see how the condensation might proceed in such a way as to produce an asymmetrical earth of the type observed. On the other hand, it is readily seen that a liquid-like earth would readily preserve any marked asymmetry produced in it by the processes of its generation. It therefore appears that surely geological arguments may be advanced to test current theories of the earth's origin.

The author has proposed a detailed theory of the origin of the solar system (10) which considers the formation of the earth to be an integral part of the normal evolution of binary star systems and, in essence, supposes that a parent star rotated so rapidly on its axis that it broke up into a double star, one component of which was supposed to recede to

infinity. During the process of break-up, tremendous tidal forces distorted the companion stars, detached the planets and transformed most of the initial angular momentum of spin of the components into orbital momentum. While still inside the Roche limit of the parent stars, the planets were broken up by tidal action in such a manner as to produce satellites. The process of generation is therefore one of division.

In addition to the obvious facts of the solar system, the observational background of the author's theory rests on such other significant facts as:

1. More than a third of all stars are double (11).

2. Certain classes of stars are known to rotate so fast on their axes that they must be approaching rotational instability (12).

3. Definite examples are known whereby angular momentum of spin is constantly being transformed to orbital momentum by tidal forces (e.g., the earth-moon system).

4. A large share of the double stars are "visual" and the components are so far separated that an increase in kinetic energy by a very small fraction of the energy necessary to bring them to their present observed configuration, will separate them to infinity (13).

5. The coronal tufts displayed at total eclipse appear to show that the sun's magnetic field, like the earth, is quite unsymmetrical (14) and hence it has probably suffered fission.

6. Certain novæ have definitely developed into multiple stars that are now receding from each other with such velocities that they must now be considered as independent single stars (15).

7. The geometrical relation of the satellites and rings of Saturn in relation to its Roche's limit shows:

a. That the tidal forces employed in the theory are adequate to produce break up.

b. And provided the planetary satellites were generated simultaneously with the planets; that Saturn (and by inference, the Earth) never passed through the gaseous state but must have behaved much as a liquid.

8. The formation of an unusual body like the moon is consistent with the theory (10).

The foregoing seeks only to outline some of the less obvious but important matters that were considered in the construction of an adequate theory. The relation of the above data to the theory is discussed in the original papers together with certain detailed theoretical considerations which will aid in the understanding of the mechanism of binary star formation.

The theory outlined above was constructed some years ago on the basis of astronomical data alone but it now turns out to be peculiarly fitted to describe the observed asymmetry of the earth and the origin of the continents. It will be necessary to note here only that the theory indicates (*a*) that the planets and the earth were generated by the formation of tidal protuberances on the outer layers of a parent star with subsequent detachment; (*b*) that the earth was formed while in a quasi liquid state.

Now the formation of a protuberance on a star by tidal deformation cannot seriously disturb the distribution of density in the outer layers and therefore its outermost regions will be made up of relatively cool material of somewhat less density than the material at the base of the protuberance which is necessarily drawn from the deeper, denser and hotter regions of the star. Thus when the tidal protuberance is finally detached and becomes the primitive earth, the internal distributions of density and temperature would be expected to be non-uniform. An earth generated in this manner will evidently possess marked asymmetries of the type observed.

The outer surface of the earth probably cooled to a nearly uniform temperature shortly after its formation, crusts formed, foundered and reformed producing in the course of thousands of years an outer shell of nearly uniform temperature. During these early stages of cooling, considerable circulation of the liquid-like earth material must have taken place because it is known from the earth's mass and moment of inertia that the densest material is near the center and it is also known that the density of the surface rocks decreases on the average with increasing altitude. Further, the average temperature within the juvenile earth must have been greater

in one hemisphere than it was in the other because of its stellar heritage and its particular mode of formation. There is considerable reason for believing that this difference in temperature persists to a degree even now. The conclusion rests on our knowledge of electrodynamics and the common presumption that the earth's core is composed of an alloy of nickle-iron. The earth's magnetic field is known to be distorted and symmetrical about an axis making an appreciable angle with and displaced about three hundred kilometers from the geographical axis (16). Any satisfactory theory of the magnetic field must attribute it to systems of electrical currents flowing in the hot interior. In order to satisfy the equation of continuity and the observed distribution of field, it is necessary to infer that the electrical conductivity of the Pacific hemisphere is appreciably greater than the rest of the earth. Whence recalling the fact that the conductivity of iron alloys decreases with increasing temperature, it is concluded that the Pacific hemisphere is cooler than the Continental hemisphere. The above argument is not as clear cut as might be desired and is offered because it is apparently the only data available which gives a reasonably definite idea of the physical state of the earth's deep interior. If one may accept the foregoing inference regarding the present state of the deep interior, it seems necessary to conclude that in the new born earth, the present Continental hemisphere must have been relatively hot compared to the Pacific.

The circulation within a heated liquid is known to increase rapidly with temperature, partly because the temperature and density gradients are likely to be large but principally because the viscosity of all liquids decreases very rapidly indeed with increasing temperature (17). Therefore, if one hemisphere happens to be at an appreciably higher average temperature than the other, then the circulation of the liquid material in that hemisphere will be very much faster than in the cooler one and segregation of the light and heavy materials will proceed much more rapidly.

Thus, notable differences in the temperature of the two hemispheres would result in different segregation patterns and light continental material would have a greater opportunity to separate out in the hotter one. One may, therefore,

understand in a qualitative way the underlying processes which produced great continental layers of approximately 50 km. thickness in one hemisphere without producing a somewhat comparable layer in the Pacific basin. A quantitative estimate of the rate of segregation does not seem possible at the present time but the observational data mentioned above show that segregation in the gross is well advanced but is not complete. An unknown part of the observed differences in the two hemispheres is probably due to the distribution of density and temperature in the parent star and to the fission process of earth formation which would be expected to accentuate any lack of symmetry in the surface layers of the parent star. The foregoing suggestions are also of assistance in understanding how one-half of the earth's crust succeeded in accumulating a large fraction of the total radioactive material.

According to the foregoing process of formation, the outer shell of juvenile earth would be expected to be non-uniform and the continental material would be concentrated on one side in a huge super continent. Now as long as the thickness of the outer shell of appreciable strength was less than, perhaps, 100 km., and its cooling had not proceeded to great depths, tangential forces on this great super continent were unimportant. But as the earth cooled and strength developed in deeper and deeper layers, marked differences in density due to the differential cooling of the oceanic and continental hemispheres disturbed the system of forces existing in the liquid-like earth and tangential forces were set up.

Now, Equation (14) expresses the stress on the margin of the continent and implies, under symmetrical conditions, that the central regions of the parent continent will be under some sort of horizontal tension if the boundary stresses are relieved. It is clear that the parent continent will break up near its center if the stresses of tension exceed the strength Q_t of the mid-continental material. Therefore, employing Equation (14) and taking $\rho = 3$ gms./cm.^{3} and $\rho_0 = 5.5$ gms./cm.^{3}, it is found that the parent continent will break up into smaller ones when

$$\frac{T^2}{R}(\rho_2 - \rho_1) = \frac{Q_t \rho_0}{2\pi\gamma\rho^2} = 1.5 \times 10^7 Q_t.$$

The ultimate strength of the earth's crust in tension Q_t is unknown; it is certainly much less than the crushing strength and probably is quite small in special regions of crustal weakness. If one adopts an apparently reasonable value for Q_t such as 10^6 dynes/cm.^{2} or about 1 kilogram of force per square centimeter, then

$$\frac{T^3}{R}(\rho_2 - \rho_1) = 1.5 \times 10^{13},$$

which is satisfied if $(\rho_2 - \rho_1)$ is taken as 0.025 gm./cm.^{2} and T as 600 km. or half of its present value. The exact values are not significant since the curvature of the earth in such a parent continent covering roughly one-third of the earth's surface is of some importance and the value of Q_t is not definitely known. However, the results do suggest that after the earth has cooled sufficiently to develop strength in the deeper layers, radially outward forces were developed in the parent continent and it would be expected to disintegrate into smaller units whose surface dimensions were more nearly comparable to the thickness of the layer; that is, of the order of, but greater than, a thousand kilometers. Nothing in the calculation suggests further details of the process except perhaps that the number of resulting continents should be small. Their particular forms were probably dependent upon the location of zones of weakness in the original shell.

Wegener has carried forward the history of the continents after the break-up and attempts to describe their specific forms, etc. This part of the problem is primarily geological and the physicist can offer little assistance in its solution.

REMARKS.

The foregoing comments and estimates lead to the conclusion that an earth formed by a fission process possesses just those features necessary to account for several outstanding properties of the earth. An earth formed by the division of a hot larger body will be non-uniform and segregation processes may be expected to modify systematically the distribution of surface materials, thus producing a large continental region. Subsequent cooling, systematically inhibited by the presence of an outer blanket of radioactive material in the continental layers appears to account well for

the contraction and formation of the Pacific basin and for an excessive value for the density of the shell in this region. Calculation of the gravitational forces arising from the asymmetry of mass distribution in the outer shell shows that these forces are of the right magnitude to bring about the disintegration of the parent continent; to transport the resulting continents toward the Pacific with a velocity of the order of one inch per year, even against a reasonably resistant margin which resists with a force of the order of 10^{24} dynes and to produce folding and overthrusting in sedimented areas in such a manner as to assist in the generation of the circum-Pacific Mountain chains.

The author proposes to discuss in a subsequent paper the application of some of the foregoing results to the complicated and difficult problem of mountain building, but it may be noted here that tangential forces of the calculated magnitude are adequate to produce sliding and overthrusting on a scale much greater than is assumed in the contraction theory of mountain building. The concentration of stress around the boundary of the relatively dense Pacific basin seems adequate to account for the generation of the entire circum-Pacific mountain chain. The problem has been considered by earlier investigators from the qualitative point of view with interesting results (2, 17).

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NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

INTENSITY REQUIREMENTS OF ULTRAVIOLET LAMPS.

At the meeting last month of the International Committee on Measurement and Standardization of Ultraviolet Radiation for Use in Medicine, at Wiesbaden, Germany, the Bureau was represented by Dr. W. W. Coblentz, a member of the committee for the United States. Doctor Coblentz, by invitation, presented a paper entitled "Physical Methods of Lightdosimetry," and, because of its direct bearing on this subject, he also recounted some of the activities of the Council on Physical Therapy of the American Medical Association, in coöperation with the Bureau, in promulgating requirements for intensities of ultraviolet lamps acceptable for therapeutic purposes. The principal facts brought out are the following:

The question of standardization had its origin in a specific request from physicians for a simple means of determining whether a lamp emits an appreciable amount of ultraviolet radiation. Hence, after due consideration, the Council on Physical Therapy of the American Medical Association adopted, and until a more practicable and reliable procedure is proposed, will use the erythemal reaction as a criterion for judging the effectiveness of an ultraviolet lamp, for the following reasons: (*a*) it is in common use as an indicator of skin tolerance to ultraviolet radiation; (*b*) the correlation of the physiologic (erythemal) reaction to ultraviolet radiation with the radiometric evaluation of the stimulus is established with sufficient accuracy to permit a calculation of the approximate time of exposure, based upon a simple measurement of the ultraviolet radiant flux emitted by the lamp; (*c*) it is a simple and practicable means of preventing severe burns when using powerful sources of ultraviolet radiation; and (*d*) it is an efficient safeguard against the fraudulent sale of lamps that emit little or no radiation of wave-lengths shorter than about

*Communicated by the Director.

3132A, generally accepted as having a specific effect in preventing rickets.

The Council does not prescribe the dosage. Its function is to keep the medical profession and the laity advised on the properties of the numerous devices offered for use in physical therapy.

In writing such a specification five years ago the Council was fully aware of the fact that the erythematogenic property of the lamp is not necessarily a measure of its healing power. However, with the widespread advertising of lamps for healing purposes, some so weak in ultraviolet radiation that 20 hours, or longer, would be required to produce a mild (if any) erythema, some action had to be taken. As shown in Doctor Coblentz's paper on dosimetry, the recent investigations confirm the earlier work showing that the spectral limits of antirachitic action are practically coincident with that of erythematogenic action. Hence, the antirachitic dosage (healing power) of the ultraviolet lamps now in use depends upon skin tolerance as determined by the erythemal reaction.

In its acceptance of ultraviolet radiators the Council makes a distinction between lamps for use by physicians and lamps for use in the home, without an experienced technician. For use in the home the Council accepts only lamps that emit little or no ultraviolet radiation of wave-lengths shorter than 2800A. This is because of the widespread belief that for general body irradiation it is desirable to confine the spectral range of wave-lengths closely to that of sunlight.

The Council's specification of the minimum ultraviolet radiant flux that a lamp must emit in order to qualify as a therapeutic agent is based upon the correlation of the erythematogenic action and the radiometric evaluation (in absolute units) of the intense and easily isolated emission line of the mercury arc of wave-length 2967A, which is used as a standard.

The Council has adopted 10 microwatts per square centimeter of homogeneous radiation of wave-length 2967A as the unit of erythemal flux, and has (tentatively) called it the Finsen Unit (F. U.); that is, 1 F. U. = 10 microwatts per square centimeter (100 ergs per cm.^{2} per sec.) of wave-length 2967A. On the basis of the Council's specification of an

exposure of fifteen minutes, it will require a flux density of 20 microwatts per cm.^{2} (2 F. U.) of homogeneous radiation of wave-length 2967A to produce a minimum perceptible erythema. The amount of ultraviolet radiation of wave-lengths shorter than and including 3132A that a source of heterogeneous radiation must emit, equivalent to 20 microwatts per cm.^{2} of homogeneous radiation of wave-length 2967A, is obtained by dividing the 20 microwatts by the erythematogenic efficiency of the source in question. For example, the erythematogenic equivalent of sea level, noon hour, June sunlight is $(20 + 0.22 =)$ 90 microwatts per cm.^{2} and for the type G mercury vapor glow lamp it is $(20 + 0.185 =)$ 108 microwatts per cm.^{2}. Data of this type were presented by Doctor Coblentz at the Copenhagen meeting of the International Congress on Light in 1932.

After the ultraviolet spectral energy distribution of a given type of lamp is known, it is a simple matter to measure by means of a differential thermopile and barium flint glass filter (as recommended by the International Committee at Copenhagen in 1932) the total flux of wave-lengths shorter than and including 3132A, emitted by a particular lamp, and thus determine whether it is acceptable.

The Council's requirements for acceptance of ultraviolet lamps have been in use for about five years. During this time there have been no difficulties or misunderstandings. Usually the radiometric evaluation of the ultraviolet intensity of a particular kind of lamp, and the calculation of the time required to produce a minimum perceptible erythema (one that disappears in 24 hours), based upon this radiometric evaluation and the erythematogenic correlation, are in close agreement with the data supplied by the manufacturer. In the one or two instances where there was a disagreement in the evaluation of the ultraviolet intensity, the manufacturer accepted the Bureau's findings in preference to his own.

In view of the differences in opinion regarding the use of the erythemal reaction in connection with the sale and use of ultraviolet lamps, it is of interest to note that in at least three instances, the above-mentioned lamp manufacturer had obtained his erythema standard by observations on a group of workers in his own factory. Nevertheless, there was good

agreement between his claims and the Bureau's tests, which would seem to indicate that, in spite of the great variations noted in erythemic sensibility of different persons, there is no great difficulty in obtaining an average value of the erythemal response, by a judicious selection of a group of healthy persons of average skin pigmentation, for use in standardizing one lamp.

The acceptance of infra-red radiators involves no difficulties since so many (of 250 to 500 watts) are on the market for heating rooms, etc. The present tendency is toward the use of tungsten filament lamps (250 to 500 watts) because of the large amount of deeply penetrating infra-red radiation of wave-lengths 8000A to 12,000A emitted.

In conclusion, Doctor Coblentz pointed out that the activities of the Council on Physical Therapy of the American Medical Association are in keeping, at least in spirit, if not in all details, with the recommendations of the International Committee on Measurement and Standardization of Ultraviolet Used in Medicine. That the Council is apparently not following more closely the recommendations of the International Committee is to be attributed to the fact that its system of ultraviolet evaluation was promulgated prior to, and is more comprehensive than, the Committee's proposals to the International Congress of 1932.

COMPARISON OF DATA ON THE IONOSPHERE, SUNSPOTS, AND TERRESTRIAL MAGNETISM.

Observations of the ionosphere made by the Bureau during the past six years have resulted in new information on the relations between radio wave phenomena and disturbances in the earth's magnetic field and the variations of sunspots, which is presented in RP913 in the *Journal of Research* for September.

The three recognized regions of the ionosphere are the E (100 to 120 kilometers high), the F_1 (200 to 230 kilometers) and the F_2 (240 to 500 kilometers). These regions are capable of reflecting radio waves back to the earth, and are responsible for long-distance radio transmission. The upper limit of the frequency which at any given time can be reflected

back to earth is known as the critical frequency, and has a definite diurnal variation. The graphs of the E and F_1 critical frequencies are symmetrical about the noon axis. This is not true of the F_2 critical frequency, which, moreover, is much more variable.

Comparison of the seasonal variations of the noon critical frequency and virtual height of the F_2 region indicates that high values of critical frequency are accompanied by low virtual heights and vice versa. Two maxima of critical frequency appear each year, approximately in February and November. Low critical frequencies are predominant in the summer. The seasonal variation of F_2 virtual height is similar to the seasonal variation of the horizontal component of the earth's magnetic field.

Annual averages of the noon critical frequencies show a good correlation with annual average sunspot numbers.

Critical frequencies of the F_2 region at midnight appear to be decreased by the occurrence of magnetic disturbances, especially in the summer.

IONIZATION OF AIR BY LENARD RAYS.

Lenard rays in atmospheric air have been measured by means of simple ionization chambers. At ordinary intensities, encountered with Lenard rays, it is impossible to saturate such ionization chambers and this has resulted in neglect of the method for practical purposes. It has been found, however, that plotting the reciprocal current against the reciprocal voltage, a straight line results, which can be extrapolated to $1/V = 0$; thereby giving the current at infinite field. A number of such cases are given in RP924 in the September *Journal of Research*. Unipolar conductivity is evident in at least one ionization chamber.

ELECTROLYTIC MEASUREMENT OF THE CORROSIVENESS OF SOILS.

Corrosion of metals in soils is accompanied by a flow of current which is discharged into the soil at the anodes or corroding areas and returns to the metal surface at the ca-

thodic areas. Since corrosion proceeds through the action of electrolytic cells, a study of the electrical properties of soil cells in which one electrode is made the corroding element, may contribute to a knowledge of the mechanism of corrosion in soils and to the development of a satisfactory test for soil corrosiveness.

The primary purpose of a study described in the September number of the *Journal of Research* (RP918) was to determine whether the relative corrosiveness of soils toward iron and steel could be predicted from measurements of the electrical properties of corrosion cells in which the electrodes were of the same ferrous material and the electrolytes were various soils of known corrosiveness. A satisfactory electrolytic test would render unnecessary the determination of various factors in corrosion, such as hydrogen-ion concentration, total acidity, and concentration of soluble salts, the influence of which on the rate of corrosion would be manifested in the electrical properties of the corrosion cells.

From measurements of current and potential in corrosion cells, either with an impressed emf or with only the emf associated with the corrosion of the anode, it was possible to arrange a large number of soils in approximately the same order of corrosiveness as that obtained by loss-of-weight tests conducted for short periods in the laboratory, and by field tests over a period of 12 years.

The essential information to be obtained from laboratory tests of soil corrosiveness is provided by measurements at various current densities of the voltage of the cell, corrected for IR drop. The average current density corresponding to the voltage range from 0 to 0.3 volt is a convenient expression of the information contained in the current density—potential curve.

The chief factors inducing corrosiveness in soils are: (1) high concentrations of soluble salts, especially those of the alkali metals, and (2) high acidity. Both of these factors increase the solubility of the hydroxides of iron and retard the formation of protective layers of corrosion products. Corrosion is relatively slight (1) in soils in which the content of bicarbonate is equivalent to the sum of the calcium and magnesium, and (2) in well-aerated soils, in which the hydrox-

ides of iron are precipitated in immediate contact with the corroding surface.

The results of the laboratory tests indicate the average extent of corrosion which might be expected on a definite area (for example, 1 square foot) of a ferrous material after 12 years exposure to soil. Since the primary cause of the failure of a pipe line is not the uniform attack of the pipe but the development of pits which penetrate the pipe wall, the results of tests of soils in the laboratory do not in themselves indicate the useful life of pipe in a certain soil, or the number of leaks which might be expected on a given section of pipe line after a definite period of exposure to the soil. Such calculations require that the laboratory data be related to the average depth of the deepest pits on a given area in a given period, and that the relations connecting depth of pit with the area exposed and the time be approximately known. Study of these relations is now in progress.

SALT SPRAY TEST FOR STAINLESS STEELS.

The so-called "salt spray" test is widely used for stainless steel. Although the test has been severely criticized as a basis for predicting the behavior of these steels under general service conditions, it may be very useful for showing whether or not the surface has been finished in such a way as to insure maximum corrosion resistance.

Recently several bars of cold rolled chromium-iron alloy (17 per cent. chromium), with surfaces ground smooth and bright, intended for outdoor exposure at an inland location, were exposed in a mist of a 20 per cent. sodium chloride solution for 24 hours. As a result, numerous rust spots appeared at isolated points over the surfaces of the bars. However, after refinishing (during which a layer approximately 1/100 inch thick was removed from all surfaces) no pitting or rusting whatsoever was observed when the bars were exposed to the same test conditions. The test, in this case, proved that, had the bars been left with the original surface finish, the maximum resistance to corrosion inherent in the material could not have been obtained.

INSPECTION AND TENSILE TESTS OF SOME WORN WIRE ROPES.

Wire ropes in service are inspected from time to time to determine when their strength has decreased so much that they should be replaced. Although great care is taken when inspecting ropes on elevators and other machines, the failure of which would endanger life or property, inspectors have had to depend largely upon judgment based on experience when deciding whether or not to take a rope out of service.

In coöperation with the special committee on wire rope of the American Society of Mechanical Engineers, the Bureau inspected and tested 229 worn ropes submitted by 79 users. The results are given in RP920 in the September number of the *Journal of Research*.

The strength was estimated, using charts prepared by the Roebling Company. It was found that the estimated strength and the actual strength were nearly the same. It is believed that by measuring the length of the worn portions of the outside wires and counting the number of broken wires in a rope, its strength can be determined with sufficient accuracy to decide whether or not the rope should be continued in service.

PENETRATION OF MOISTURE INTO MASONRY WALLS.

The tests of rates of penetration of water through masonry walls, described briefly in Technical News Bulletin No. 226 for February 1936, are being continued. The walls are about 50 in. high and 40 in. long and 4, 8, or 12 in. in thickness. After aging and drying for from one to three months, they are being subjected to a test in which the water penetrates under the forces of capillarity and gravity only. Water is applied by means of a spray at the top of a wall, causing a continuous film of water on the exposed face of the wall. Observations of the performance of a wall include the time for dampness to penetrate the wall, the period for leakage (if any) to start and the rate of leakage through the wall.

Following the completion of the capillary tests the walls are redried and then are tested under conditions resembling exposure to a strong wind and heavy rain. Water is again applied to one face near the top of a wall, in the same manner

as in the capillarity test, producing a continuous film of water on the exposed surface. The effect of a strong wind is simulated by maintaining an air pressure of 10 lb. per sq. ft. on the exposed face of the wall. Some of the walls are being subjected to a third test in which water is applied by means of atomizers, while a difference in air pressure of 10 lb. per sq. ft. is maintained between the exposed and unexposed faces of the wall. In this test the rate of application of water is controlled to produce an effect similar to that of exposures to a rain of moderate intensity accompanied by a strong wind.

As expected, the rate of water penetration was increased by maintaining the air pressure on the exposed faces of the walls. The time for dampness to appear on the unexposed face was reduced, usually to less than one-half that required in the capillarity test. Similarly when leakage occurred, it started sooner and usually was in larger volume in the pressure test than in the capillarity test.

The performance of the walls was influenced by the quality of the workmanship, the thickness of the walls, the kind of brick, etc., but of these the quality of the workmanship was the most important factor. All of the walls of class B workmanship having open (unfilled) interior joints and flush-cut face joints leaked; whereas most of those with class A workmanship, having solidly filled interior joints and tooled face joints, showed little or no leakage. Of the walls built with a nearly impervious brick, none of those with class A workmanship leaked during the period of testing, which ranged from 1 to 14 days, but all of those with class B workmanship leaked, either through the facing or the backing, within 15 minutes after the start of the tests. The effect of differences in workmanship was somewhat less pronounced for the walls with more absorptive bricks, but the majority of those built with class A workmanship did not leak, whereas all with class B workmanship leaked in less than one hour. The quality of the workmanship had a similar effect upon the performance of the walls with structural tile backing and a facing of absorptive bricks.

For the walls of class A workmanship, those with the nearly impervious bricks gave the best performance. However, most of the data available to date are results of the first two

tests in which water is applied at a rate greater than would normally result from exposure to natural rainfall. The walls of the more absorptive bricks have given relatively better performances in the third tests with the water being applied at a more normal rate. There was not an important difference in the performance of the wall built with the different kinds of brick and class B workmanship.

Each of the four cement-lime mortars used in the walls was satisfactory to the masons; all were considered to have satisfactory working properties. Although the rates of moisture penetration through the walls were, on the average, slightly less for walls with the cement-lime mortars rich in portland cement than for those rich in lime, the differences were too small to be significant.

PROPERTIES AND SERVICEABILITY OF SILK DRESS FABRICS.

A study of the serviceability of 69 silk dress fabrics was started during the spring of 1930 by the American Home Economics Association with the coöperation of college students and teachers, and the Bureau. The students purchased silk fabrics in the local stores, made dresses for themselves, and observed the performance of the dresses in service, all as a part of their class assignments.

Samples of the fabrics were analyzed and tested at the Bureau, and 23 of the dresses showing the results of wear were examined, along with reports on their behavior in service. In addition, five reports of serviceability, submitted without the corresponding dresses, were examined.

Good correlation was found between the results of laboratory "performance" tests on color fastness, breaking strength, and aging characteristics of the fabrics, and the behavior of the dresses in service. In addition to these properties, resistance to yarn slippage at the seams and in the fabric is important. No relation between the serviceability of the dresses and the construction or price of the fabrics was indicated.

These results point to the practicability of evaluating dress fabrics by performance tests and of setting up standards for serviceability on this basis. Methods for determining

these important properties were recently brought together in Commercial Standard CS59-36, "Woven Dress Fabrics—Testing and Reporting," at present available in mimeographed form, and which will soon be obtainable as a printed publication.

EMPIRICAL RELATION BETWEEN THE ATOMIC DIMENSIONS AND THE MELTING AND SUBLIMATION POINTS OF THE NOBLE GASES, HALOGENS, AND ELEMENTS OF THE SULPHUR GROUP.

In comparing the melting points of the noble gases, halogens, and elements of the sulphur group it has been found that, of these groups, those elements which have analogous differences in atomic structure show an apparent simple relationship between their melting points and their atomic dimensions, the differences in the melting points being proportional to their respective differences in atomic radii.

Further, it was found that for these elements with analogous differences in structure an apparent proportionality exists between the differences of the atomic radii on the one side and the respective differences of sublimation points at low pressure on the other. These relationships are reported more fully in RP915 in the September number of the *Journal of Research*.

180,000 Meshes per Square Inch.—(*Engineering Progress*, Vol. XVII, No. 9.) A fact which is perhaps not generally realized is that, of all woven fabrics, the finest are produced by the wire weaving industry. A peak achievement of particular interest is a wire netting manufactured by Oskar Eilhaner, Metallgewebefabrik, Neustadt, Germany, in as much as it is the finest wire fabric, and therewith altogether the finest of all fabrics so far made. This wire netting has 180,000 meshes per sq. in. It is used for the sifting and straining of powders and liquids. The wire itself is 0.009 in. in diameter. By way of a comparison, it may be stated that a human hair is from 0.0024 to 0.004 in. thick. The manufacture of these wires is in itself a noteworthy feat. Since it is essential that all mesh openings are absolutely equal each wire must be run through a separate opening in the reed. This is therefore different from ordinary textile weaving, where threads can be run through the reed openings a number at a time. To produce the requisite fineness, the reed must therefore have 650 dents per running inch.

R. H. O.

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LIBRARY NOTES.

RECENT ADDITIONS.

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BOOK REVIEWS.

AN INTRODUCTION TO ATOMIC PHYSICS, by John Thomson, M.A., D.Sc. 228 pages, 14 × 22 cms. New York, D. Van Nostrand Company, Inc. Price $3.50.

The subject of this book is one which has undergone new concepts in recent years, resulting already in much of practical everyday value and untold value in the future. From some of these discoveries a great deal of speculation has arisen, so that physicists in general have centered their attention more and more on atomic physics. Truly it is a frontier that promises adventure. But like all knowledge, a true appreciation of it requires a thorough understanding of fundamental facts and theories. The aim of this book is just that, and a perusal of it reveals a performance to marked degree.

There are three parts to the book. In part one, there is developed in a logical manner the conception of atomic structure which is obtained from the interpretation of experiments. In the author's opinion the interpretations offered are the only ones which will withstand the tests of further experiments. In so far as all judgments are made in terms of concepts previously within our consciousness, the atomic structure developed is hypothetical. There is no definite picture of atomic structure—a model built upon this basis would mislead in some of its properties although it may be suggestive. This leads to the treatment in part two of the book which gives an account of the most outstanding attempts to form atomic models and thus to link up the apparant disconnected facts catalogued in part one. In the first two chapters in part two the Bohr atom is considered and in the subsequent chapters the fundamental principles of wave mechanics are developed, which eliminates some of the assumptions required by the Bohr theory. It is mentioned in passing that all the results of wave mechanics can be obtained by means of the formally equivalent statistical mechanics due to Heisenberg and improved by Dirac and Born. A short theoretical account of the De Broglie waves associated with a moving particle is also given.

Part three contains a review of molecular, atomic and nuclear radiations which serves to indicate the most important lines of attack on the problems of atomic structure. It includes treatments on atomic optical spectra, the formation of molecules, characteristic X-rays, and radio activity. There is an appendix covering the theory of relativity, following which are examples illustrating the use of some of the formulæ and a suggested list of references for further reading. An index completes the book.

This book can be recommended to those who wish to gain a clear idea of the essential simplicity of atomic phenomena and to see in their proper perspective the new principles brought into being by modern investigations.

R. H. OPPERMANN.

CARBON DIOXIDE, by Elton L. Quinn, and Charles L. Jones. American Chemical Society Monograph Series. 294 pages, illustrations, tables, 16 × 23.5 cms. New York, Reinhold Publishing Corporation, 1936. Price $7.50.

This book is one of the Monograph Series of the American Chemical Society and represents an assemblage of available information in a usable form. Those who have been and are interested in carbon dioxide will immediately recognize

that published literature on the subject is both voluminous and widely scattered and therefore often difficult to obtain, to say nothing of the problem of digesting its content and breadth. Undoubtedly the book at hand, Carbon Dioxide, will satisfy the needs of many students, research workers, and industrial workers. Because of its very nature its use should save much time and provide ready information.

There are eight chapters each covering to a remarkable extent a portion of the subject. The first, as introductory, covers the early history of carbon dioxide, the scientific and industrial development. Its occurrence in nature is treated in chapter two followed by chapters on the physical and chemical properties. In the fifth chapter carbon dioxide and vital processes is discussed wherein there is included the stimulation of plant growth, the indirect fertilization of plants, therapeutic uses, use as an escharotic, and as an insecticide. The chapters on the manufacture of liquid and the manufacture and distribution of solid carbon dioxide contain a mine of valuable information, likewise the last chapter on the uses of commercial carbon dioxide.

An appendix gives a list of patents of many countries subdivided into the classifications of manufacture, applications, melting and vaporizing, and storage and transportation. There is also included here tables of physical data calculated to English engineering units. An author and subject index completes the book.

The authors undoubtedly have had a tremendous task in the writing of this book. That they have successfully produced a work invaluable is very evident. The method of construction used, the style of presentation of the subject,the breadth and completeness of coverage, all make this work a most welcome addition to this type of literature.

R. H. OPPERMANN.

CHRYSLER CORPORATION NUMBER, AMERICAN MACHINIST, MAY 20, 1936. Management Policies, Production Methods, Plant Services, Associated Activities. Reprint, unpaged, 23 × 20 cms. New York, American Machinist.

This book is a reprint of the May 20, 1936 number of the periodical American Machinist. Illustrated articles describe the management policies with relation to engineering, safety, industrial relations and production; the manufacturing methods with reference to forging and stamping of parts, heat treating and machining, welding and body finishing of automobiles; the plant services including material handling, maintenance and stores; and the associated activities of the great Chrysler organization. The latter activities include the supplying of parts to keep customers contented, the manufacture of Dodge trucks, of marine engines, of bearings that need not be oiled, air conditioning equipment, etc. The book is a remarkable exposition of organization and manufacturing in a large automobile production scheme.

R. H. OPPERMANN.

PRINCIPLES OF ELECTRIC AND MAGNETIC MEASUREMENTS. Part I—Electricity, by P. Vigoureux. Part II—Magnetism, by C. E. Webb, 392 pages, illustrations, 15 × 23 cms. New York, Prentice-Hall, Inc., 1936. Price $5.00.

This is a technical book in which thoroughness is emphasized. As a text it shows quite a contrast with a text on the same subject of ten or more years ago. The content is larger on each of the two subjects and the trend of reasoning is most modern. Divided into two parts, each part has its own author, both of the British National Physical Laboratory.

The larger part of the book is, of course, that devoted to electricity. In it there are eleven subdivisions. After defining units and standards there is discussed the action between electric charges leading from the torsion balance to the electroscope and electrometers to electrostatic instruments. Next, magnets and currents in magnetic fields is taken up, followed by the heating action of currents, the potentiometer, networks of conductors, electrolysis, electromagnetic induction, the thermionic tube, radio frequencies and electric charges—all with a view to giving an insight into the fundamentals of instruments for measurement or methods of measurement.

The second part of the book is devoted to magnetic measurements. First there is consideration given to a review of the properties to be measured. Necessarily in this, reference is made to subdivisions in the first part of the book but there is no lost effort. The Ballistic and Magnetometer methods of testing magnetic materials are covered, the production of intense magnetic fields, the effect of temperature on magnetic properties, magneto-electric and magneto-optic effects etc. are studied. A comprehensive subject index completes the book.

The book is intended to acquaint students of physics or electrical engineering with the principles and practice of experimental electricity and magnetism. It should prove useful to the tester and research worker in helping him to grasp the general principles underlying measurements, and to apply them.

R. H. OPPERMANN.

A MANUAL OF PHOTO-ELASTICITY FOR ENGINEERS, by L. N. G. Filon, D.Sc. 140 pages, diagrams, 13 × 19 cms. Cambridge, University Press, 1936. Price $1.50.

This is a book written especially for the use of photo-elastic methods by practical investigators in order to explore stress distributions. The author makes note that this book is not an abridgement of a previous book, "Treatise on Photo-Elasticity" by Coker and Filon, which volume is complete from the physicist's as well as the engineer's standpoint. As the title implies the present volume merely gives enough information for the practical side of model construction and for observation.

The 121 pages of text are divided into six parts, beginning with a treatment on polarized light to give an understanding of its properties in-so-far as they are revelant. Then in logical order there follows discussions on uniform stress, optical exploration of non-uniform stress, the construction of a model for photo-elastic observations, the polariscope and the optical system, and the independent measurement of $P + Q$.

In the conclusion the author states, "The great bulk of photo-elastic investigations of two dimensional stress-distributions, the majority of which are due to Prof. Coker have been carried out by the combined use of the polariscope and the lateral extensometer. So far, the method of finding P and Q separately from the optical data alone (described) has been used only exceptionally. In view of its simplicity, and of its requiring no additional apparatus, it might be more extensively employed."

"Provided the observations are carried out with reasonable care and the precautions recommended are observed, engineers need have no hesitation in using this method of exploration of stress and may confidently rely upon its results."

R. H. OPPERMANN.

REICHSVERBAND DER AUTOMOBILINDUSTRIE E. V., Schrittmacher der Wirtschaft, Vier Reden zur Internationalen Automobil- und Mottorrad-Austellung, Berlin, 1936. 32 pages, 16.5 × 24 cms.

Since the automobile exhibition in 1933, Germany has experienced pronounced strides in this industry. In the present year, 1936, in Berlin, there was another exhibition by this industry. This pamphlet contains the four keynote speeches at the opening and in the halls of the exhibition. The speakers were der Führer, der Geheimrat Dr. Allmers, Generaldirektor Hagemeier, and der Reichspost- und Reichsverkehrsminister Freiherr v. Eltz-Rübenach. The pamphlet should make very interesting reading.

R. H. OPPERMANN.

VIERSTELLIGE TAFELN DER KREIS- UND HYPERBELFUNKTIONEN, SOWIE IHRER UMKEHRFUNKTIONEN IM KOMPLEXEN, berechnet und erläutert von Robert Hawelka. 109 pages, diagrams, 22 × 30 cms. Braunschweig, Vieweg & Son.

Engineers who often have use for tables in calculations with relation to curves will immediately see the value of this book. It is of particular value in calculations of alternating currents and its use greatly facilitates the operation. There are tables of sines, tangents and arcs together with helpful explanations and drawings. One can obtain directly the arc and area functions with a minimum of difficulty. The numerous instructive suggestions and formula are clear and certainly worth while, for they not only clarify prerequisite mathematical knowledge but enable the most efficient use of the tables. The entire book can easily be used by English and French speaking engineers as well as the German.

R. H. OPPERMANN.

TELEVISION, COLLECTED ADDRESSES AND PAPERS ON THE FUTURE OF THE NEW ART AND ITS RECENT TECHNICAL DEVELOPMENTS, vol. I, July 1936. 452 pages, plates, tables, 15 × 23 cms. New York, RCA Institutes Technical Press.

Television has been a dream of man's fancy from the beginnings of knowledge, occupying the attention of the scientifically inclined since the passage of electrical impulses between two given points has held significance. The point by point procedure so far fundamentally necessary for the definition of eye

pictures brought from a distant point by electrical means has until very recently been the reef on which all practical efforts have foundered. Continuity of vision dictates a speed of repetition of impulse which when multiplied by the factor required for good definition and acceptable scope of the scene to be transmitted results in speeds and frequencies beyond the range of mechanical terminal apparatus.

Within recent years development of electrical devices has provided levers of nearly zero mass, control practically instantaneous in action, and methods for propagating impulses having infinitely improved possibilities. Many recent investigators have availed themselves of these developments in their studies of the television problem.

The subject treatise, for it can be so considered, is a compilation of the endeavors of many investigators in the organization of the R. C. A. The contents include twenty-five articles covering practically all phases of the subject.

Opening considerations naturally are directed to general factors, the place which television might occupy in our everyday life and the practical requisites to establish such conditions. Relations, both necessary and advisable with present radio broadcasting are considered and from this subject a number of technical investigations of the propagation characteristics in the frequency regions which have been indicative are described.

The character of image acceptable to the eye and an analysis of the conditions necessary to obtain this are treated at length. All of the discussions so far enumerated are of rather general character. The remaining topic given careful and lengthy treatment constitutes the major development in this art within recent years. The development of electrical devices has resulted in possibilities for television perhaps as yet only slightly realized. A stream of electrons under suitable conditions constitute a weightless pointer, moved instantly at will and providing for the first time a satisfactory substitute for the cumbersome and complicated mechanical systems which have been a most serious stumbling block.

Television is by no means around the next corner in so far as public enjoyment of it is concerned; however, this symposium clearly indicates that many of the technical corners have been rounded. There remain corners involving finances, public policy and questions of standardization. These are serious problems yet to be solved but the technical development of a television system through radio broadcasting has been completed to a fair degree of satisfaction.

The articles include many as technical as could be desired, a number of interest to the science dabbler and others which are sufficiently expressed in everyday language to be worthy of thoughtful reading as general information.

WILLIAM G. ELLIS.

NEL CINQUANTENARIO DELLA SOCIETÀ EDISON (ON THE FIFTIETH ANNIVERSARY OF THE SOCIETÀ EDISON), 1884–1934. By Various Authors. 4 volumes, illustrations, 23.5 × 31 cms. Milan, Società Edison.

This work, which the Società Edison of Milan, the oldest (and still one of the largest) among electric public utilities of the Continent, has published upon the initiative of its Managing Director, Signor Giacinto Motta, to celebrate its Golden Jubilee, is the most comprehensive and thorough attempt hitherto made to trace the history of the technical and economical development of the electric

power industry. The treatment of each subject was entrusted to a particularly qualified author. The general editorship rested with Prof. Giorgio Mortara of the Milan University, who has also made some of the more important contributions.

The First Volume, as its title indicates ("Fifty years evolution of hydraulic structures, prime movers, electric machinery and transmission lines"), is purely technical in character and illustrates the evolution undergone by the vital parts of generating (both hydro and steam) and transmission plants. Part one of the Second Volume is devoted to the general economic problems of the electric power industry and the greater part of the Second and the whole of the Third Volume are devoted to the development of the electric industry. Italy, the United States of America, Germany, Great Britain, France, Canada, Switzerland, Sweden, Norway, U.S.S.R. and Japan are considered in succession, and thus it is possible to follow the evolution of the electric industry in relation to both the economic characteristics of consumption and the power resources in each individual country. The investigation is accompanied by a wealth of statistical tables, which are drawn almost entirely from first hand sources, assembled by the Research Department of the Società Edison.

The Fourth and last Volume contains two monographs. The first illustrates statistically the economic development of the city of Milan, which witnessed the birth of the Società Edison. The second monograph deals with the history of the Company, which from the first modest steam power plant put into operation on June 18, 1883, has grown up to the present great combine which goes under the name of Edison Group: it operates today not less than 149 hydroelectric and 20 steam power stations, all feeding in a 130 kv "grid," which totals 1800 circuit miles of transmission lines and supplies current to a large part of Northern Italy, having an area greater than the whole of Switzerland.

The volumes are profusely illustrated. Numerous charts, diagrams and graphs add to the interest of the whole work.

The Istituto Grafico Bertieri of Milan has done the printing and binding.

R.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 557, Preliminary Tests in the N. A. C. A. Free-Spinning Wind Tunnel, by C. H. Zimmerman. 18 pages, tables, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

Typical models and the testing technique used in the N. A. C. A. free-spinning wind tunnel are described in detail. The results of tests of two models afford a comparison between the spinning characteristics of scale models in the tunnel and of the airplanes that they represent.

The models are built of balsa wood and ballasted with lead to the proper mass distribution. A clockwork delayed-action mechanism is mounted in the model to move the control surfaces during the spin.

In steady-spin tests, observations are made of the rate of rotation and of the air speed necessary to hold the model at test height. Moving-picture records are taken from which the spinning attitudes are obtained. In recovery tests, moving-picture records are taken of the model from the instant the controls move until recovery is effected or failure to recover is definite.

The models of the XN_2Y-1 and F_4B-2 airplanes gave good approximations to the spinning characteristics of the airplanes, in both steady spins and recoveries. Since these models were scaled from somewhat similar biplanes, no conclusions are drawn as to the reliability of model results in general.

Report No. 560, A Simplified Application of the Method of Operators to the Calculation of Disturbed Motions of an Airplane, by Robert T. Jones. 13 pages, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

A simplified treatment of the application of Heaviside's operational methods to problems of airplane dynamics is given. Certain graphical methods and logarithmic formulas that lessen the amount of computation involved are explained.

The problem of representing a gust disturbance or control manipulation is taken up and it is pointed out that in certain cases arbitrary control manipulations may be dealt with as though they imposed specific constraints on the airplane, thus avoiding the necessity of any integration whatever.

The application of the calculations described in the text is illustrated by several examples chosen to show the use of the methods and the practicability of the graphical and logarithmic computations described.

Report No. 561. Effect of Nozzle Design on Fuel Spray and Flame Formation in a High-Speed Compression-Ignition Engine, by A. M. Rothrock and C. D. Waldron. 12 pages, plates, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

Fuel was injected from different types of injection nozzles into the combustion chamber of the N. A. C. A. combustion apparatus, operated as a compression-ignition engine; high-speed motion pictures were taken at the rate of 2,200 frames per second of the fuel sprays and the combustion. Single-orifice nozzles of 0.008-, 0.020-, and 0.040-inch diameter, and multiorifice nozzles having 2, 6, and 16 orifices were tested. Nozzles having impinging jets and slit orifices were also included. The photographs indicate that the rate of vapor diffusion from the spray is comparatively slow and that this slow rate of diffusion for combustion chambers with little or no air flow prevents the compression-ignition engine, with the present methods of fuel injection, from giving the high performance inherent in the high compression ratios. The sprays from multiorifice nozzles destroyed the air movement to a greater extent than did those from single-orifice nozzles. It is concluded that high performance cannot be realized until the methods of distributing the fuel are improved by means of the injection-nozzle design, air flow, or both.

CONSTELLATIONS. Prepared by the Department of Astronomy of The Franklin Institute. 32 pages, illustrations, 15.5 × 23 cms. Philadelphia, Institute, 1936. Price thirty-five cents.

To those who have recently visited the Fels Planetarium in Philadelphia, this booklet is not unfamiliar, but for the information of others who have not visited here it is a revelation of the universe in which we are living. Star maps are shown,

one for facing north and one for facing south for each month of the year with much descriptive matter on the different visible stars. By the use of this information, one can go out doors on a clear night and derive much appreciation from the skies and what they contain, at any time of the year. Instead of the skies containing a mass of stars about which we know nothing, a knowledge of the position of the various stars is obtained, their names, mythology in connection with them, groups or constellations, the bright stars of the months, etc. The skies are made a thing of greater beauty because of the ability of greater appreciation.

Aside from this practical as well as fascinating part of the booklet, there is also to be found here other information; a table of the solar system which shows for each of the planets its distance from the sun, its diameter, mass, volume, density, number of moons, its year, day, and its mean orbital velocity; a table showing astronomical distances; and a description of a planetarium.

The booklet may be taken as a practical handbook directly contributing to that thing sometimes termed "culture," a general knowledge of things about us that makes for more enjoyment of life.

R. H. OPPERMANN.

CUGLE'S TWO-MINUTE AZIMUTHS, second volume, by Charles H. Cugle. 603 pages, 21.5 × 28 cms. New York, E. P. Dutton & Co., Inc., no date. Price $6.00.

This is the second volume on this subject, destined to fill a great need in navigation. The first volume embraced latitudes of 0° to 35° and declinations of 0° to 23° and was reviewed in these columns some months ago. The present book embraces latitudes of 35° to 65° and declinations of 0° to 23°. There are given six rules for computing time azimuths in the tables. It is the author's belief that the two minute intervals of time will do away with all interpolations required in the finding of azimuths.

R. H. OPPERMANN.

TELEVISION WITH CATHODE-RAYS, by Arthur H. Halloran. First Loose-Leaf Edition, unpaged, 13 × 18.5 cms. San Francisco, Pacific Radio Publishing Company, 1936, price $2.75.

This is a loose leaf pocket size text book of ten chapters written in terms which can be understood by radio amateur operators and service men. The text constitutes the lecture notes for a course on television given under the auspices of the Extension Division of the University of California.

It starts with explanations on the use of the cathode-ray oscillograph as a voltmeter and proceeds through the fundamental theory of electrostatic effects, electromagnetic, resistive, and impedance effects, thus developing the fundamental theory in terms of electronic motion. There is given an interpretation of a resonance curve as the relation between the tangent and cosine of the phase angle, thereby facilitating exact computation of circuit response to any off resonant frequency. The purpose according to the author, is to enable the reader to handle the instrument intelligently before introducing the complexities of its adaptations to television. Next the concept of radiation is developed, followed by electron optics and the production of television images.

The discussion is confined to the systems developed by Zworykin and Farns-

worth. The purpose of the loose leaf arrangement is to allow the insertion of supplementary sheets regarding new developments and more advanced phases of the subject.

R. H. OPPERMANN.

MODERN ALCHEMY, by Dorothy M. Fisk, 171 pages, illustrations, 14 × 21 cms. New York and London, D. Appleton-Century Company, Inc., 1936. Price $1.75.

Here is a book that truly belongs to that class which translates the language of the physicist and chemist into the every day language of the layman thereby affording an opportunity for all of average intelligence to become familiar with modern wonders already established and with the work of scientific pioneers on the brink of even greater achievements. Such familiarity with science not only makes for greater appreciation but as scientific progress is accelerated and affects our daily lives to a greater and greater extent, it is not going too far to say that it will become of necessity that some such knowledge be acquired.

The book at hand is an account of the progress of the art. It starts with a review of the earliest efforts of man in physical and chemical observations and developments and progresses from these times of the Egyptians and Chinese gradually up to the time of the discovery of the atom. Then the electrical nature of the atom is taken up and the discovery of radioactivity. The transmutation of the elements is discussed in a very interesting manner from early times when the artificial production of gold was sought to the present when with our larger store of knowledge the subject is even more fascinating. Apparatus is described for hurling projectiles at unbelievable speeds for the purpose of atom smashing and the accomplishment of results heretofore thought nothing short of magic.

The book is interestingly written, well illustrated and contains a useful index.

R. H. OPPERMANN.

THEORY OF LUBRICATION, by Mayo Dyer Hersey. 152 pages, tables, illustrations, 15.5 × 23.5 cms. New York, John Wiley & Sons, Inc. London: Chapman & Hall, Ltd., 1936. Price $2.50.

"Roger Williams, who chose Providence for his residence three hundred years ago, and whose deeds of valor are now being celebrated in these parts, wrote a Dictionary, or as he called it, a Key, to the Indian Language; which, he said, 'happily may unlocke some Rarities concerning the Natives themselves, not yet discovered.' He then goes on to remind us that 'A little Key may open a Box, where lies a Bunch of Keyes.' To the uninitiated, the equations of the hydrodynamic theory are a kind of Indian language. Perhaps this book may serve as a key, and the references (noted) as 'A Bunch of Keyes' to a better understanding of the facts of Lubrication." So quotes the author in the preface of this book. That he has in truth furnished the necessary key is very evident on examination. The work is addressed to physicists, engineers, investigators and teachers of engineering rather than directly to the undergraduate. It is a remarkable outline of the theory of lubrication divided into six parts. Foundation is laid in Chapter I, "Historical Introduction," in which there is treated the subject from ancient times to Thurston and Petroff, the work of Tower and Reynolds and the earlier investigations by Kingsbury. The development of thrust bearings, friction

measurements on journal bearings, and other preformance characteristics are discussed.

The following chapters cover in order, viscosity and its relation to friction, the classical hydrodynamic theory, dimensional theory with applications, and temperature rise in bearings.

The concluding chapter is devoted to the problem of oiliness, its concept, definition, and hypothesis to explain its causes. Here are treated the requirements to be met by oiliness tests, oiliness machines, indirect tests, numerical scales for oiliness, etc.

The author has a gift of presenting his topic in an impressive manner. The work is well illustrated with drawings and curves. No little weight should be given to the references cited throughout the book as from these, as supplementary reading, the reader will have no difficulty in amplifying the statements given in the text. Readers of the JOURNAL OF THE FRANKLIN INSTITUTE, interested in the subject of lubrication, will recall articles printed therein recently, which constitute the major portion of this book. So much was thought of these articles that the Institute after careful deliberation awarded the Louis E. Levy Medal to the author for them.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Electronic Television, by George H. Eckhardt. 162 pages, illustrations, 15 × 23 cms. Chicago, The Goodheart-Willcox Company, Inc., 1936. Price $2.50.

Constellations. Prepared by the Department of Astronomy of The Franklin Institute. 32 pages, illustrations, 15 × 23 cms. Philadelphia, The Franklin Institute, 1936. Price 35 cents.

Television with Cathode-Rays, by Arthur H. Halloran. Loose-leaf edition, unpaged, illustrations, 13 × 18 cms. San Francisco, Pacific Radio Publishing Co., Inc., 1936. Price $2.75.

Modern Alchemy, by Dorothy M. Fisk. 171 pages, illustrations, 14 × 21 cms. New York, D. Appleton-Century Co., Inc., 1936. Price $1.75.

Theory of Lubrication, by Mayo Dyer Hersey. 152 pages, illustrations, 15.5 × 23.5 cms. New York, John Wiley & Sons, Inc. London, Chapman & Hall, Ltd., 1936. Price $2.50.

Cugle's Two-Minute Azimuths, by Charles H. Cugle. 602 pages, 21.5 × 28.5 cms. New York, E. P. Dutton & Co., Inc. Price $6.00.

Memento de l'Industrie du Caoutchouc, par F. Jacobs. 444 pages, tables, 13.5 × 21 cms. Paris, Societe d'Editions Techniques Cillard, n.d.

Medicine and Mankind, edited by Iago Galdston, M.D. 217 pages, 13.5 × 19.5 cms. New York, D. Appleton-Century Co., Inc., 1936. Price $2.00.

Bernardo Marasco, Cinematografia Sonora la Registrazione Cinematografica dei Suoni. Monografie de L'Industria. 96 pages, illustrations, 13.5 × 19 cms. Milano, L'Industria, 1936.

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the supervision of O. E. Kiessling and H. H. Hughes. 1136 pages, tables, 15 × 23.5 cms. Washington, Government Printing Office, 1936. Price $2.00.

National Bureau of Standards, Directory of Commercial Testing and College Research Laboratories. 55 pages, 19 × 27.5 cms. Washington, Government Printing Office, 1936. Price 15 cents. Vitrified Paving Brick, 18 pages, 15 × 23.5 cms. Washington, Government Printing office, 1936. Price five cents.

Canada Dominion Bureau of Statistics, The Asbestos Mining Industry and the Asbestos Products Industry in Canada, 1935. 19 pages, tables, 22 × 28 cms. Annual Report on the Mineral Production of Canada during the Calendar Year 1934. 301 pages, tables, 16.5 × 24.5 cms. Ottawa, King's Printer, 1936.

Canada Department of Mines, The Canadian Mineral Industry in 1935. 100 pages, illustrations, 16.5 × 25 cms. Ottawa, King's Printer, 1936. Price 25 cents.

United States Coast and Geodetic Survey, Special Publication no. 203, First and Second Order Triangulation and Traverse in Minnesota (1927 Datum), by Walter F. Reynolds. 411 pages, tables, 15 × 23 cms. Washington, Government Printing Office, 1936. Price 60 cents.

National Advisory Committee for Aeronautics, Technical Notes, No. 576, Tank Tests of a Model of the Hull of the Navy PB-1 Flying Boat—N.A.C.A. Model 52, by John M. Allison. 10 pages, figures. No. 577, Friction of Compression-Ignition Engines, by Charles S. Moore and John H. Collins, Jr. 10 pages, figures. No. 578, Full-Scale Wind-Tunnel and Flight Tests of a Fairchild 22 Airplane Equipped with a Fowler Flap, by C. H. Dearborn and H. A. Soule, 19 pages, figures. 3 pamphlets, 20 × 26 cms. Washington, Committee, 1936.

Bell Telephone Laboratories, Monographs: B-928, Corrosion Behavior of Painted Iron and Inhibitive Action of Paints, by R. M. Burns and H. E. Haring, 16 pages. B-932, Copper and Iron Alloys—The Tensile, Electrical and Corrosion Properties, by Earle E. Schumacher and Alexander G. Souden, 18 pages. B-933, Effect of Electric Shock on the Heart, by L. P. Ferris, P. W. Spence, B. G. King and H. B. Williams, 45 pages, tables. B-935, Chemical Studies of Wood Preservation—II, by C. J. Frosch, 25 pages. 4 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1936.

CURRENT TOPICS.

Historic Trinity Tower Now Rests on Rock.—R. G. SKERRETT. (*Compressed Air Magazine*, Vol. 41, No. 8.) Historic Trinity Church, in New York City, has faced the western end of Wall Street for ninety years. It is a brownstone structure of the so-called English Perpendicular Gothic style and in plan is generally rectangular with a width of 79 ft. and a length of 166 ft. At one end is the tower, which, so far as its support is concerned, is virtually independent of the main body of the structure. It rises 134 ft. 4 in. above the ground surface and is surmounted by a spire, 140 ft. 1 in. high. This is topped with a 6 ft. cross. The tower is set upon a foundation of hard brownstone-rubble masonry laid in cement mortar extending below the ground surface about 12 ft. and beneath this is a sand and gravel stratum. Settlement has occurred under the foundation so that the tower became out of plumb to such an extent that its tip is 17 1/8 inches eastward of where it should be. Underpinning had to be resorted to in a way that would not weaken the structure. To do this it was necessary to go down 58 to 65 feet from the bottom of the tower foundation to the mica schist bedrock. Sand, quicksand, hardpan, and bowlders lying below the ground-water level had to be penetrated. The work could be done only by employing pneumatic caissons, and each caisson was made just large enough to hold one man—the air pressure at any depth being sufficient to prevent the inflow of water. The steel cylinder above each caisson was lengthened by the addition of short sections of steel tubing as the cylinder was forced downward with jacks that reacted against the weight of the superposed tower. After landing on the surface of the bedrock each cylinder was sealed at the bottom and subsequently filled to the top with concrete forming a column that transmits its share of the load of the tower to basic rock and doing after 90 years for Trinity what was done for each of the neighboring modern buildings before any part of their structures mounted above the ground surface.

R. H. O.

A 150,000 Ampere Contactor.—W. SCHAELCHLIN describes in the *Electric Journal*, Vol. 33, No. 8, such an apparatus used in pipe welding where heavy currents at low voltage must be broken. It has 150,000 amperes continuous capacity and 200,000 amperes

intermittent rating at 10 volts direct current, and is capable of closing frequently and opening the full current with practically no signs of contact burning. Direct current is supplied by a homopolar generator. The contactor is inserted in the circuit of the high welding current and timed to close and open the circuit the instant after the pipe reaches the electrodes and immediately before it leaves them, thus permitting a welding process with a minimum waste of pipe and no burning of the electrodes. The contractor is in reality several units in parallel, each having its own busbar to insure satisfactory division of load. Correct relative timing of the four contactors used in this case, is obtained by means of a common shaft operated from a single driving mechanism.

R. H. O.

Grapefruit Byproducts.—At Winter Haven, Fla., is located the Department of Agriculture's Citrus Products Laboratory. In the four years since the laboratory was established, chemists there have shown that high quality salad oils, as well as solid fats may be obtained from grapefruit seed, which is about one-third fat or oil.

That is not all this group of investigators has done. Splendid wines have been made from citrus juices by adding sugar. They also have developed a method for canning orange juice with a "bite" approaching that of fresh juice, a method which also greatly improves the flavor and keeping quality of canned grapefruit juice.

C.

Propane, the Perfect Fuel.—A. LUDLOW CLAYDEN at the Kansas City Spring Meeting of the American Chemical Society lists investigational results whereby he and his colleagues concluded that propane is an ideal fuel for internal combustion engines. It stands very high compression, thereby giving good thermal efficiency; it is perfectly clean, leaving no combustion chamber deposits upon burning; it can be distributed perfectly through a manifold, which is not true of any wet gas. If a high ratio of power to engine weight is desired, propane should make such possible to a degree greater than that with any other fuels.

C.

Soybeans—America's Future Greatest Crop?—According to N. F. TRUE, speaking at the symposium on the chemistry and technology of soybeans at the American Chemical Society Spring Meeting, literature on soybeans spans almost 5000 years, as the

first records available were written in 2838 B.C. In addition to being considered the most important cultivated legume in China, it likewise was held as one of the five sacred grains essential to the maintenance of ancient Chinese civilization. Soybeans also rated as a very important element in the materia medica of that day and, strange as it may seem, present scientific research on the utilization of this product confirms many of the records.

Chemical studies of soybeans reveal that their protein has a nutritive value practically equivalent to that of milk. The oil contains unsaturated fatty acids rendering it of value to the paint industry. Besides their valuable mineral content soybeans contain significant quantities of vitamins B and G.

Especially important is the use of soybeans in infant diet materials as the sole source of protein for those children who are allergic or hypersensitive to animal protein. Of equal importance soybeans are finding wider and wider applications in the dietary of the diabetic, as the chemical composition of this vegetable makes it peculiarly adapted to this type of diet.

Soy sauces are made from fermented beans as are many other foods, popular chiefly in the Orient. Several of those introduced in this country, especially by returned travelers, include: miso, both red and white types, which is one of the commonest breakfast foods for children; to-fu, frequently termed soybean cheese by travelers; and natto, also commonly called a cheese.

It is an interesting microbiological comparison that most of these fermented soya foods, as developed in the Orient, are the products of mold fermentation (the Aspergillus group being the dominant type of mold involved), whereas in the Occident the popular fermented foods such as cheese, pickles, etc., are the result of bacterial fermentation.

The production of soybeans in this country has, according to M. M. DURKEE, developed from a crop comparatively unknown only a few years ago to one of over 39,000,000 bushels in 1935. The oil is obtained from the bean by high-pressure expellers, hydraulic pressing, or solvent extraction, the latter being the most efficient. When fresh, the refined oil is sweet, has a low fatty acid content, and can be made almost water-white. A considerable volume of refined oil is now marketed as a salad or cooking oil. Large quantities of soybean oil are used in the manufacture of vegetable shortenings wherein it is blended with cottonseed or other oils up to 10 to 15 per cent. One characteristic of the oil which at present limits its use somewhat is the gradual development of a socalled reversion flavor. The prevention of this flavor

is a major problem to the industry and has not been solved satisfactorily as yet.

C.

Magnetic Separation of Seeds.—(*I. and E. C.*, Aug. 20, 1936.) The Hungarian correspondent writes of a patent assigned to G. LORÁND covering the magnetic separation of the seeds of weeds, especially of plantain from valuable Trifolium seeds. A mixture of 12.5 to 25.0 parts of magnesium chloride or calcium chloride, 50 parts of calcium oxide, and 25.0 to 37.5 parts of iron powder is given to the seeds. The chemical agent is adsorbed on the surface of plantain seeds only and thus they are attracted by the magnets, leaving the Trifolium seeds behind.

C.

Rehabilitating an Incline.—M. S. GILBERT. (*Transit Journal*, Vol. 80, No. 8.) Change after change has taken place in Cincinnati, Ohio, as the various forms of transportation have been modernized during the past 60 years, but the Mt. Adams incline has remained the same until recently. Illustrations show two car structures hauled up and down the side of Mt. Adams by means of cables. They are used to carry street cars. Nearly 2,000,000 passengers a year ride up or down this incline, one of the few of this type still in existence. It is 98 ft. long with a 28.9 per cent. grade. The vertical lift is 261 ft. It has four draft cables each 1,200 ft. long and 1¼ in. in diameter, consisting of 114 strands of steel wire wound around a ½ in. hemp cord. In addition to the draft cables there is the 1⅜ in. auxiliary or safety cable of the same construction connecting the two cars, acting as a means of balancing load. The cables are made especially for this incline to give both strength and durability, each one having a breaking strain of 67 tons. They are wound around two large drums, 14 ft. in diameter, and are fastened to the two 35 ton cars. The drums are driven by two high pressure Corliss engines, permitting a speed of the cables and hence the two incline cars, one ascending while the other decends on an opposite track, at 650 ft. per minute. The complete rehabilitation project included the rebuilding of the incline car trucks, installation of a new safety cable, extensive renewal of timbers in the incline plane trestle and repair of the machinery and boilers in the power plant. Involved in the job, of course, was the problem of not suspending operation for too long a period.

R. H. O.

A New Device for Resuscitation Training.—W. C. GRANT (*American Gas Association Monthly*, Vol. 18, No. 8). The application of the prone pressure method of resuscitation has always been accompanied by a certain element of uncertainty in technique. Different subjects require different degrees of pressure to restore them to consciousness. This is due to a difference in physique and their condition at the time of unconsciousness. In the case of a person electrocuted, the muscles of the body have a tendency to stiffen while with a drowned person the muscles are relaxed. A child requires less weight and pressure than an adult, a woman perhaps less than a man. The operator, however, has heretofore had no scientific means of determining just what pressure to apply and what results he was obtaining during the training period. Mr. C. I. Langdon, of the Lone Star Gas System, Dallas, Texas, has designed a device by which the weight pressure exerted on the subject, the air volume, and timing are recorded simultaneously upon a single chart, held in such a position that it can be observed conveniently by the operator. This chart informs him continuously during the operation of the results he is achieving. The apparatus is believed to be invaluable in developing proper technique in that it records the action of the operator. If his technique is wrong, for instance, if his hands are not in the proper position—too close to the spine, too high on the ribs, too low down on the hips—the weight recorded is liable to be too heavy without forcing out a proper volume of air. By changing his hands the correct spot can be found where a definite volume of air, for instance, 500 cubic centimeters, can be produced on the average subject with not more than 25 pounds pressure.

R. H. O.

Manufactured Colored Aggregate for Architectural Concrete.—Volume two, number three, of *Architectural Concrete*, a publication of the Portland Cement Association, contains an article on this topic which is timely and informative. Laboratory research and investigation of sources of manufactured materials suitable for concrete aggregate have resulted in making commercially available highly colored aggregates economically. In these aggregates the color is a product of the internal fusion or vitrification of coloring component with a stable base and is as unchangeable as it is in mosaic tile, fine porcelain or cathedral glass. It is this permanently colored aggregate that gives lasting brilliant color to architectural concrete through a technique which produces a surface which is composed almost entirely of aggregate particles. There

are two types of such aggregates—ceramic and vitreous. The former is made from high grade clays and other ceramic raw material by processes similar to those used in producing pottery and china ware. While the colors are bright and clear, they are characteristically soft. The vitreous aggregates are made with materials and by methods similar to those used in producing porcelain frits or glass. These are distinguished by their luster and brilliance. Certain colors can be produced only with this type. Tentative standards of colors have been set up, although any shade can be produced. A thoroughly practical technique has been developed for using these colored aggregates in architectural concrete through the medium of cast stone. From the standpoint of design, this material may be conceived as a mosaic in which aggregate particles are substituted for the usual tesseræ and set en masse through the medium of cast stone instead of singly.

R. H. O.

Sound Wave Timing Locates Underground Rock.—(*Construction Methods*, Vol. 18, No. 7.) By precise timing of sound waves racing through earth and through earth and rock, engineers of the Bureau of Public Roads have developed practical field methods for determining the distance below the ground surface to solid rock. These engineers have perfected an instrument by which measurements can now be made on the surface. The measuring instrument is a highly sensitive electrical device known as a seismograph. Accurate results are obtainable by measuring the speed with which an impulse from the explosion of a buried blasting cap or small charge of dynamite travels through the ground. Such an impulse will travel through soil at a speed of 1,000 to 6,000 ft. per second but the speed through rock is 16,000 to 20,000 ft. per second. A cap is exploded in the ground and at the same time the electric current exploding the cap causes a record to be made with precise apparatus for measuring time. Special detectors are placed at different distances from the explosion and pick up the impulse as it comes through the ground. The detectors are electrically connected with the time recording device and the time of travel of the impulse from the explosion can be measured to a small fraction of a second. Knowing the speed of travel and the time taken it is possible to calculate how far the impulse went downward through soil before it encountered rock. This method has been used extensively in prospecting at considerable depth for oil. Elaborate and costly apparatus has been used. The Bureau of Public Roads has now developed simplified apparatus that is giving excellent results.

R. H. O.

The Acquisition of Skill in Industry.—An editorial in *Engineering*, Vol. CXLII, No. 3685, is devoted to Report No. 73 of the Medical Research Council of Great Britain entitled The Acquisition of Skill: An Analysis of Learning Curves. It testifies to the care being bestowed by research workers upon hypotheses relating to intensive teaching in preparation for the workshop, and it conveys a hint of what has yet to be performed by those confronted by this problem of industrial education. So far as can be judged, the attention of scientific investigators in their recent efforts has been directed chiefly to theories applied to workers upon repetitive tasks, and to conditions underlying efficiency and economical methods of learning in that field. It is one of the purposes of the learning curves, with which the report is essentially concerned, to determine if with increase of skill, personal differences between individuals tend to disappear or persist. The curves are also useful in investigating such questions as the most economical length of interval which should be interposed between successive practice periods when a new task is being learned. On this point, Mr. J. M. Blackburn, the author of the report, is of opinion that the task is learned with the fewest number of repetitions if rest periods are introduced, but in a shorter time if the instruction is "massed," although in this latter case greater effort is needed.

R. H. O.

California Walnut Growers Use Conditioned Storage.—(*Refrigerating Engineering*, Vol. 32, No. 3.) It is said that there is nothing new under the sun. Maybe so—but at least there is something different. In the spring of this year the California Walnut Growers Association built what is believed to be the largest air-conditioned cold storage room in existence, capable of holding 17,000,000 lb. of walnuts. The temperature maintained in this room averages between 36° and 40° F. and the relative humidity is kept close to 65 per cent. The plant is located at Vernon, a suburb of Los Angeles. The building is a one-story structure of modern design, and measures 700 ft. by 400 ft. and some 30 ft. high. The refrigerated storage room itself is 600 × 175 × 22 ft. The floor is concrete. The walls have a 6 in. granulated cork insulation; on the east there is a demountable panel wall, containing 4 in. of shredded redwood bark insulation; the ceiling is also insulated with this same material. One of the unique parts of the refrigerating system is the method of air-conditioning developed by P. A. Sherer. Some 6,000 yards of unbleached muslin folds are installed in redwood frames, and through these the return air passes en route to the section of two large fans, each 75,000 cu. ft. per min.

capacity. Cold brine is distributed over the surface of the muslin from supply headers. This air-conditioning compartment is separately insulated from the main refrigerated room and is approximately 22 ft. wide by 150 ft. long arranged in two floors. Refrigeration is supplied by two 9 in. by 9 in. ammonia compressors of the enclosed type driven through V-belts by motors. Either is capable of maintaining the temperature but both are required for quickly lowering the temperature after new shipments are put in storage.

R. H. O.

Grass Drying by the Kaloroil System.—(*Engineering*, Vol. CXLII, No. 3686.) Grass drying by artificial means is a recent development in agriculture and one that may have considerable future. Drying experiments have been proceeding at Sutton, near Hereford, England, with a plant designed by Kaloroil Burners, Ltd. The vital points when drying grass are, firstly, that the drying must be carried out with a flow of air at low speed, so that the full quota of moisture can be absorbed in its passage and its heat surrendered, and secondly, to preserve its nutritive value, the grass must be submitted to high temperatures for a short time only. It must therefore be kept agitated so that it dries evenly and prolonged heating will not be required to remove damp patches. Two methods are adopted, one, an ordinary hop kiln and one by the use of a specially designed drying unit. The hop kiln method is employed to make additional use of existing plant. An oil burning furnace fired by a twin oil burner giving a smokeless flame is installed. The time of drying varies with moisture content of the grass, but it is calculated that two kilns 20 ft. square with grass of 78 per cent. moisture will produce 5 tons of dry grass in two eight-hour shifts. The unit dryer is a two-stage process consisting of a hopper for the first stage from which the grass falls when sufficiently dry into a wire gauge drum. This is rotated at about six r.p.m., requiring about 5 h.p. The methods used, the exact effect on farm management, and the ultimate commercial values of the products are still indefinite, but it is stated there is abundant market for dried grass as fodder. The drying process, however, has a wider scope, including hay, grain and seeds.

R. H. O.

A New Plastic.—(*Chemical and Metallurgical Engineering*, Vol. 43, No. 9.) Outstanding among the papers presented before the joint symposium on Synthetic Resins and Plastics at the American Chemical Society Meeting was a contribution by Dr. H. R. Dittmar

of the Ammonia Dept. of the duPont Co. which described a new water-clear plastic strong as glass, flexible and non-shattering. This new product, which has been given the name "Pontalite," is a polymerized methyl methacrylate. A factory for its manufacture is under construction and commercial production is scheduled to begin early in 1937. Although softer than glass, the new plastic is hard enough to be widely useful. It is thermoplastic and can be sawed, cut, drilled and polished, as well as molded readily to any desired form. A liquid intermediate variety can be poured into molds and hardened and in this way castings are readily made. Solutions of the plastic as well as the liquid intermediate form have been used successfully as impregnants for wood, cloth, paper, stone and electrical apparatus. Materials treated in this way are much more resistant to water, oils, and chemicals. Because the methyl methacrylate is compatible with other resinous materials such as nitrocellulose, rosin, ester gum, certain types of Bakelite, several glyptals, chlorinated rubber, courmarone resins, etc., it is believed to have a very broad application in specialty coating field. Relatively low specific gravity (1.19 to 1.20) together with its high mechanical strength, makes it of interest to the aircraft industry.

R. H. O.

Gunning for Bacteria.—(*Electric Journal*, Vol. 33, No. 9.) Ultra-violet rays, like fire, can be man's best friend or enemy. About two days after one has spent a few lazy hours partially unclad in the sun, ultra-violet has the aspect of an enemy. On the other hand, properly applied, these rays are among the best weapons we have in the never ending struggle against those we cannot see—bacteria. The device that is proving so effective in this struggle emerged from the research laboratory with the name Sterilamp. It is a long slender tube that emits energy in a relatively narrow band in the ultra-violet region. In operation it emits a dull bluish glow. Because of the low power input required it operates at but a very few degrees above room temperature. The lamp uses 350 volts, requiring as an adjunct a small transformer. The Sterilamp is being used in several of the food industries. For instance, it has been found that with these lamps mounted inside meat showcases and with high humidity, it is unnecessary to maintain low temperatures—meaning saving in refrigeration costs—and the meat remains in better condition, with much better appearance, and much less loss of weight over a period of several days than in the ordinary refrigerated show-case. Likewise, by exposing cakes and their wrappers to the rays from Sterilamps for a few seconds at the bakery, the formation of mold is delayed several days—greatly

increasing the salable life of pastry. How these things are accomplished have an easily understood explanation. By sterilizing the air surrounding a food bacteria has no opportunity to attack and spoil the food.

R. H. O.

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